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Properties and treatment of pond water supplies

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PROPERTIES AND TREATMENT OF POND WATER SUPPLIES

by

Ted LeRoy Willrich

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INTRODUCTION

General Situation Summary

Critical water problems exist in the United States. Water supplies are frequently inadequate, highly mineralized, unpalatable or polluted, or a combination of these characteristics. Problems of unsatisfactory water quantity and quality from rural and urban water supplies have intensified in recent years. Factors contributing to the problems are:

1. Increased water consumption in modernized rural homes and on mechanized farms.

2. Depleted supplies due to an extended drought from 1952 through 1958.

3. Increased demand for water of acceptable physical, chemical and biological quality for all consumptive uses.

4. Expansion of urban developments with the resulting congestion of individual water and sewage disposal systems.

A lack of adequate or satisfactory well water has caused many rural and urban families to use some type of surface water for their domestic water supply. Treatment of surface water supplies is essential since they are frequently high in suspended sediment and grossly contaminated. Many pathogenic organisms are water-borne, and surface water supplies are easily infected. Consequently, adequate treatment of surface water supplies requires disinfection to destroy bacterial, viral and protozoic pathogens. Food-spoilage and milk-spoilage organisms also should be destroyed by disinfection if the water is to be used in the preparation of frozen foods or to cleanse dairy utensils.

State health departments and universities are becoming increasingly aware of the water problems and the need for treating individual farm and urban water supplies effectively and economically. At least 14 states have published circulars on surface water treatment. All states have publications concerning the construction and protection of well water supplies. Since 1945, research investigations concerning pond water treatment have been conducted in at least nine states.

Slow sand filtration has been frequently recommended for the removal of suspended sediment from surface water supplies because it requires less attention and operator experience in comparison to other filtration methods. However, recommendations for filtration are based primarily on municipal experience rather than on research observations of typical rural installations. Other types of filters have been investigated, but available information is inconclusive concerning their effectiveness.

Similarly, several methods for water disinfection have been studied. Chlorination is generally recommended in preference to silver, ozone, ultraviolet and heat treatment methods. Reasons for this preference are:

1. Chlorination is the least expensive method.
2. Chlorination provides a residual germicidal effect.
3. Chlorine solutions are nontoxic in normal dosages.
4. Chlorine residual can be measured by a simple test to determine adequacy of treatment.
5. Chlorination has an established and accepted use criteria.

The successful operation of all filtration and chlorination systems are subject to mechanical and human failure and to the variability of raw water quality. Therefore, particular caution must be exercised in recommending treatment equipment that provides an adequate margin of safety, is practically foolproof and requires a minimum of attention. Based on existing information, super-chlorination followed by slow sand filtration will provide the best opportunity for adequate and continuous disinfection and filtration of surface water supplies.

Purpose of this Study

The reasons for initiating this study were:

1. Consumptive use of water to supply the needs of urban and rural homes and farms has increased rapidly in the past 25 years. Frequently, this water is of inferior quality.

2. Many underground water sources are either inadequate or undependable in quantity, or undesirable or unacceptable in quality over a major portion of Iowa. This is particularly true in southern Iowa.

3. Ponds function satisfactorily as storage reservoirs for surface water, particularly in the southern half of Iowa where underground water resources are limited.

4. Pond water, although possessing some undesirable properties, is frequently preferred to well water and is being used as a supplemental or only source of water for many household and farmstead uses in Iowa and other states.

5. Satisfactory treatment processes to make pond water of acceptable quality have not been completely developed or successfully applied.

6. The qualitative and quantitative properties of pond water have

not been adequately identified.

The objectives of this study were to define more exactly the problems of pond water treatment as they pertain to Iowa, to identify pertinent qualitative and quantitative properties of pond water as they are affected by natural conditions and treatment methods, to observe and test field installations, to recommend treatment equipment and operational procedures based on available research data and to make suggestions for additional research on pond water treatment.

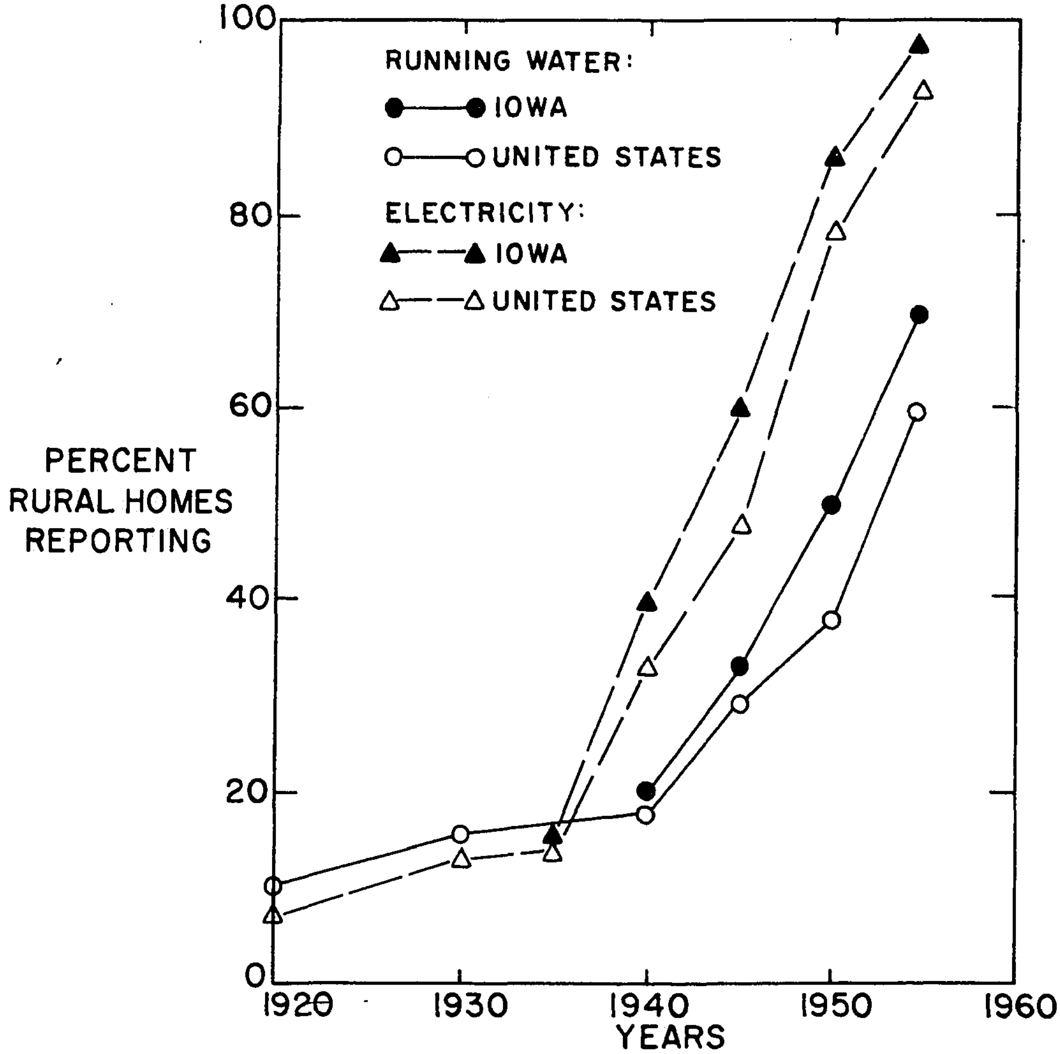
The Water Supply Situation in Iowa

Quantity requirements

Existing water supplies frequently do not satisfy the demands of modern rural homes and farms. A modern home requires from three to five times more water than a home without plumbing and a pressure water system. The increased availability of electric power has influenced the modernization of rural homes within the past 25 years. The influence of rural electrification on the introduction of running water into rural homes is indicated in Figure 1. An estimated 99 percent of Iowa farms are currently supplied with electric power and an estimated 78 percent of the nondelapidated rural homes have running water. A critical problem of inadequate and undependable water supplies exists on many of these farms.

The increased availability of electric power has also promoted the modernization and mechanization of livestock production units. Increased mechanization has reduced the number of man-hours required to produce a unit of livestock product. Consequently, livestock numbers and the

Figure 1. Electricity and running water in the rural homes of the United States and Iowa.


100
80
60
40
20
0
PERCENT
RURAL HOMES
REPORTING
RUNNING WATER:
IOWA
UNITED STATES
ELECTRICITY:
IOWA
UNITED STATES
1920
1930
1940
1950
1960
YEARS

amount of water consumed by these livestock has increased per farm unit. Continuously available water, as the result of an automatic pressure water system, tends to increase the daily water consumption by animals. Improved sanitation practices frequently require large quantities of water. Approximately 20 gallons of water per day is required for each producing cow to clean a milking parlor and milkroom satisfactorily, and to sanitize the bulk milk tank and milking equipment. About 1 to 4 gallons per day per hog is required to flush and carry wastes from a hog finishing building. Additional modernization and mechanization of the rural homes and farmsteads will correspondingly increase water demands in the future.

Failure of water supplies has also occurred due to inadequate rainfall. An extended drought caused a cumulative deficiency of almost 40 inches at Des Moines for the 10-year period, 1949-1958 (80). A water shortage existed throughout Iowa in general, and particularly in southern and southwestern Iowa where ground water supplies are least favorable, Figure 2.

A lack of adequate and dependable farm water supplies is indicated by information which shows that Agricultural Conservation Program cost-sharing was applied on the construction of 9,200 farm wells in 1956 and 5,700 wells in 1957.[1]

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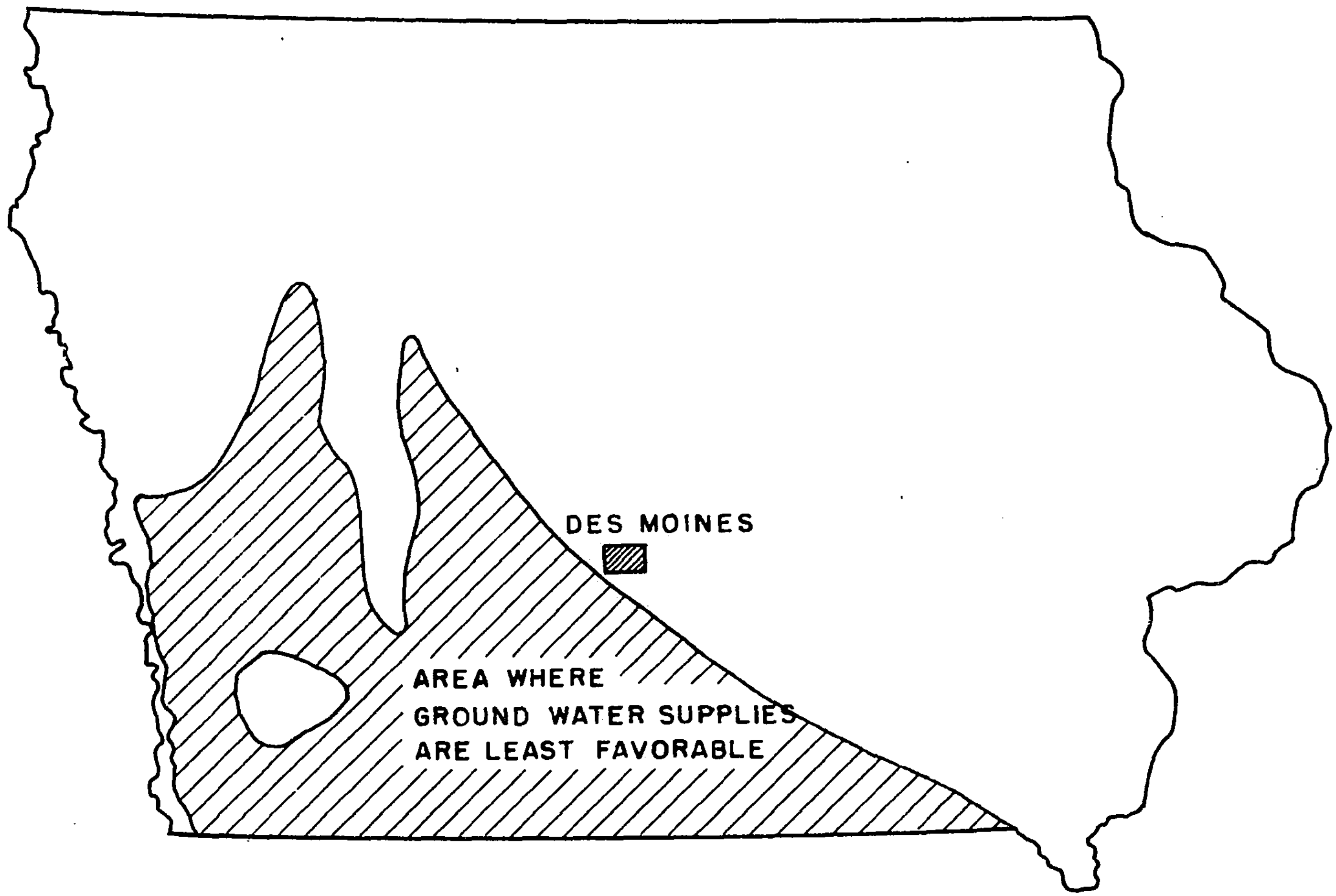
[1]Cornell, Dewey, Agricultural Stabilization and Conservation Committee, Des Moines, Iowa. Information on ACP cost-sharing practices. Private communication. 1960.

Figure 2. Unfavorable area for the development of ground water supplies in Iowa.


DES MOINES
AREA WHERE
GROUND WATER SUPPLIES
ARE LEAST FAVORABLE

Quality requirements

Water of increasingly higher quality is being demanded by the rural population. Water of acceptable physical, chemical and biological quality is needed to protect human and livestock health, for Grade A milk production, for the preparation of home-processed foods and for esthetic reasons. A water supply free of undesirable organisms, tastes, odors, turbidity, color and dissolved minerals is certainly desirable. An estimated one-third of the Iowa farm families have a food freezer, and one-fifth of the milk produced in Iowa is for the Grade A market. Therefore, food-spoilage organisms, as well as pathogenic organisms, should be destroyed by adequate treatment of water used in conjunction with the handling or preparation of food products on the farm. An increasing need for improved water quality exists.

Water supply from underground sources

The quality of well water is frequently unacceptable from a public health standpoint. A high percentage of the shallow wells is unsatisfactory or unsafe due to an excessive bacteria or nitrate concentration. A survey conducted cooperatively between the Iowa Extension Service and the State Department of Health in Humboldt County, Iowa, in 1952 was summarized with the following results:[1]

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[1]Boyles, X. P., State Department of Health, Regional Office, Fort Dodge, Iowa. Data on Humboldt Co. well survey. Private communication. 1959.

Water quality	No. of samples	Percent of total
Satisfactory	127	54
Unsatisfactory	46	20
Unsafe	60	26

Of the sampled wells, 83 percent were drilled wells, 10 percent were dug wells, 6 percent were bored wells and 1 percent were driven wells.

Water containing 10 mg/l or more of nitrate nitrogen is considered unsafe for infant feeding due to the possible cause of methemoglobinemia (3). Some evidence indicates that high nitrate content can also produce adverse intestinal pathological conditions resulting in chemical diarrhea and a diuretic effect.[1] A 1946 survey (49) indicated a fairly high incidence of excessive nitrate concentration in dug wells in rural Iowa. Of 243 dug wells which were sampled, 28.9 and 15.3 percent were found to contain more than 20 and 50 mg/l of nitrate nitrogen, respectively. From the samples submitted to the Iowa State Hygienic Laboratory for bacteriological analysis, nitrate nitrogen levels as high as 400 mg/l are occasionally observed.[2]

Records maintained by the Iowa State Hygienic Laboratory indicate that rural water supplies frequently test unsafe for human consumption.

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[1]Morris, R. L., State Hygienic Laboratory, Iowa City, Iowa. Information on nitrates in water supplies. Private communication. 1958.

[2]Blomgren, Carl, State Department of Health, Regional Office, Council Bluffs, Iowa. Information on high nitrate analysis well water supplies. Private communication. 1961.

For the first seven months of 1953, the following percent of all private well water samples analyzed by the Laboratory were of an unsafe bacteriological quality:

Month	Percent unsafe samples
January	35
February	35
March	41
April	42
May	49
June	58
July	66

From such information, the Iowa State Department of Health estimates that between 65 and 75 percent of all farm wells are contaminated and frequently produce water of unsatisfactory bacteriological quality.

Water supply situation from surface sources

Ponds and reservoirs serve as the principal sources of water for many farms and municipalities in southern Iowa (70). Existing impounded supplies were drastically lowered during the drought years from 1953 to 1959 (5). Whereas the area in the vicinity of Des Moines has an estimated mean annual surface runoff of 5-1/2 inches (61), little or no runoff occurred in 1953, 1954 and 1956. Annual precipitation observed at the Des Moines airport station for these 3 years was 20.0, 22.0 and 17.1 inches, respectively (80). Most watersheds are not expected to produce runoff when the annual precipitation falls below 22 inches (10).

Due to the failure of existing wells and many of the smaller ponds, an estimated 50,000 new ponds were constructed in Iowa during the 1950 to 1960 decade. Most of these ponds were constructed in southern Iowa due to the general lack of available underground water supplies and the existence of soil types which are low in permeability and consequently retain impounded surface water. In this area, Figure 3, the soils are generally suitable for dam construction, the substrata are quite impervious, and the topography permits large volumes of water to be stored at a reasonable cost. Suitable sites are available in other parts of the state, but they are not as extensive as in southern Iowa.

Types of ponds constructed in Iowa

As described by Calkins (13), four types of ponds are constructed in Iowa. These include:

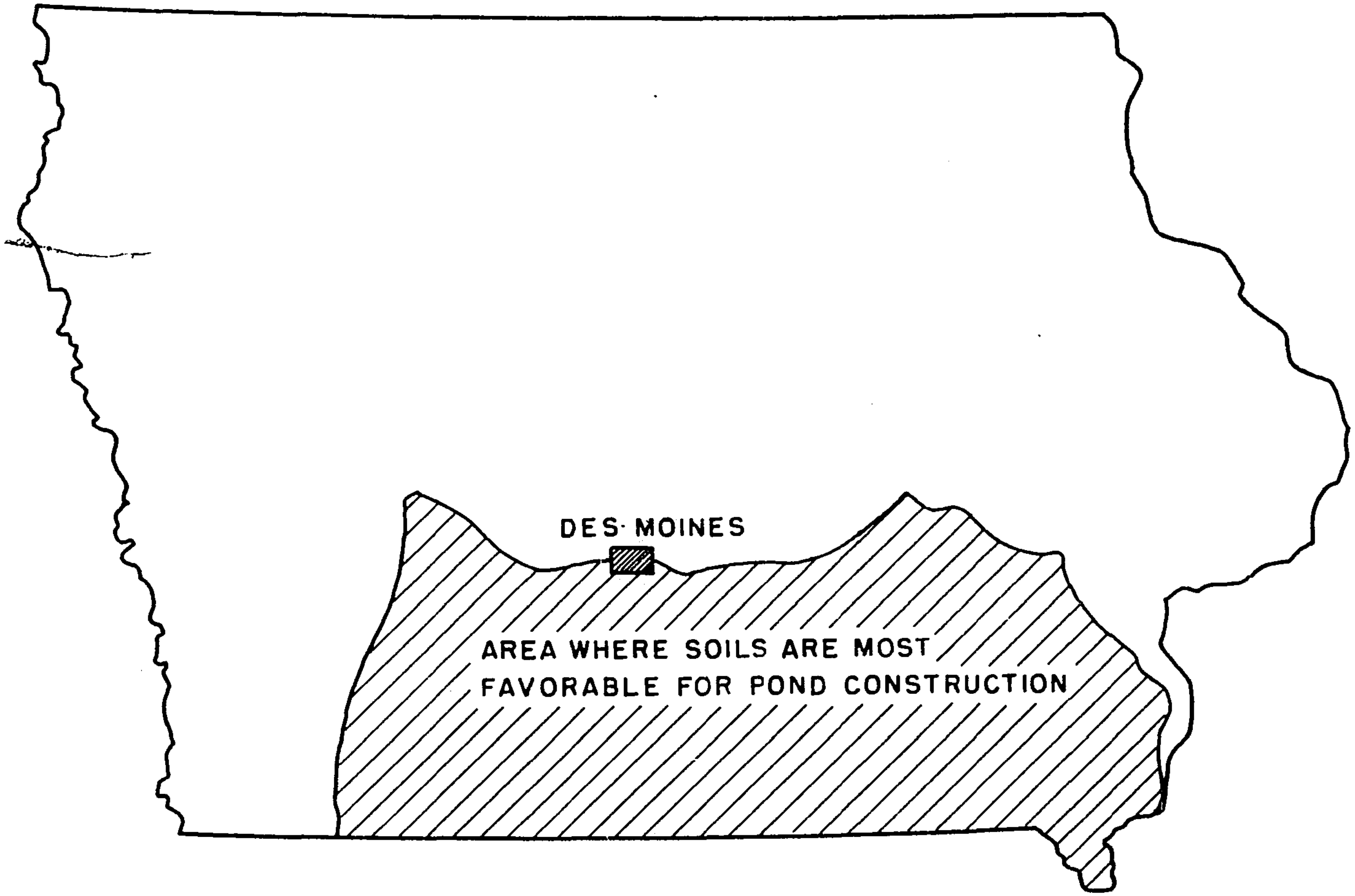
1. Dugout ponds fed by ground water.
2. Spring-fed ponds.
3. Off-stream ponds.
4. Ponds fed by surface runoff.

Dugout ponds, sometimes referred to as pits, are constructed where the ground water table is near the surface. Since dugout ponds are recharged with ground water, the water is frequently highly mineralized. Gastler and Olson (28) recommend that dugout water containing more than 10,000 mg/l of soluble salts should not be used for livestock watering. A salt concentration of less than 5,000 mg/l is preferred.

Spring-fed pond water may also be high in dissolved minerals. The chemical analysis of spring-fed pond water will vary with the distance of travel and the soil and rock minerals with which the water comes in contact. However, spring-fed ponds generally contain water considerably lower in turbidity and color than ponds which are fed by surface runoff.

Off-stream ponds are located adjacent to a stream so that water may

Figure 3. Favorable area for the construction of farm ponds in Iowa.


DES MOINES
AREA WHERE SOILS ARE MOST FAVORABLE FOR POND CONSTRUCTION

be diverted or pumped from the stream to fill the pond. The quality of water stored in an off-stream pond is entirely dependent on the variable quality of the stream flow.

The pond fed by surface runoff is the type most common in Iowa. Water quality in these ponds is influenced by the type of cover and management of the watershed which contributes surface runoff to the pond. The construction of the pond and the management of the pond and pond site also affect the properties of the pond water. In general, pond water from surface runoff is lower in dissolved minerals than water in ponds or wells fed by ground water. However, the water requires treatment for the removal of color, suspended solids, tastes and odors. All surface water requires disinfection for the destruction of undesirable biological life if it is to be used for drinking and for food preparation in the home.

Pond Water Usage in Other States

Due to the unacceptable quality or unavailability of underground water, pond water supplies are being used extensively in other states. Daniel (23) reported that there were more than 150,000 farm ponds in Oklahoma. Also, pond water supplies are used occasionally by schools, motels, country clubs and other public and private institutions that are not serviced by municipal water systems.

About 1,400 pond water filters were constructed in Missouri from 1950 through 1953 (32). Of these filters, 252 were installed to supply drinking water and the remainder were built to obtain a water supply for other consumptive uses. A large majority of the farm families were drinking the filtered pond water without disinfection.

A 1956 survey showed that over 9,000 Ohio farmers had a critical water problem and that about 300 were using pond water for domestic or milkhouse use (42).

These examples illustrate the extent of pond water use in other states. Pond water supplies are being used due to necessity or in preference to less desirable underground water supplies.

The Significance of Water-borne Organisms

Water supplies, particularly pond water supplies, contain a variety of living organisms. Fortunately, most of these organisms are harmless, and water-borne pathogenic organisms are relatively few in number since water is an unnatural environment for pathogens. The natural environment of pathogens is the human body and the bodies of other warm-blooded animals. However, some diseases are transmitted by water-borne pathogens in water polluted by excreta from humans and animals. Pond water supplies are subject to pollution from wild animals using the pond and its watershed, from domestic animals grazing in the watershed or given direct access to the pond, and from human sewage and barnyard drainage from uncontrolled portions of the watershed.

Destruction of water-borne pathogenic organisms, particularly bacterial pathogens, has been the principal criteria for acceptable water treatment from a public health standpoint. The incidence of typhoid fever, caused by a water-borne bacterial pathogen, was at one time the standard indicator of the general level of water sanitation for municipal water supplies. However, the reported cases of typhoid fever dropped to an insignificant level in comparison to previous records when municipalities in the United States started filtering and disinfecting their water supplies in the early 1900's (3).

An analysis of water-borne disease outbreaks for the years 1938 to 1945 indicated that there were less than 1,400 cases of typhoid fever in the United States for this 8-year period (24). Reported dysentery cases were 8,622. Gastroenteric cases, which generally are not reported to health authorities, totaled over 101,000. Private water supplies were responsible for 70 percent of the total number of outbreaks of these three water-borne diseases. The causes of pollution in private water supplies were primarily due to well contamination or defects in the water distribution system. These defects included cross-connections, back-siphonage and lack of disinfection following installation or reconstruction of a well.

The number of typhoid fever cases reported annually in Iowa during the past 10 years has ranged from 12 to 61 cases.[1] Most cases have been traced to carriers, although water-borne outbreaks are not uncommon. Of perhaps greater concern than the reported cases of the more common enteric diseases are the cases of infectious hepatitis, brucellosis, leptospirosis and tularemia which are traceable to causative, water-borne pathogens. The last three diseases are more commonly known as diseases which infect livestock and wild animals. However, these

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[1]Heeren, R. H., State Department of Health, Des Moines, Iowa. Information on typhoid fever and infectious hepatitis cases in Iowa. Private communication. 1961.

diseases can also be transmitted to man either by direct contact or by other avenues of infection including the consumption of infected water (3, 82).

The epidemiology of infectious hepatitis has received closer scrutiny since several outbreaks have occurred, apparently due to a water-borne organism (60, 65). In 1954, Iowa recorded the highest number of infectious hepatitis cases, 3,619, of any state in the nation.[1] Five hundred eight cases were reported during the first 3 months of 1961.

Iowa has the highest rate of human infection by brucellosis in the nation. Of the 741 cases reported by the U. S. Public Health Service in 1960, Iowa had 307 cases or 41 percent of the total.[2] An outbreak of leptospirosis in Iowa was reported in the fall of 1959 when 36 people were infected after swimming in a creek to which diseased cattle had access.[3] These cases of brucellosis and leptospirosis indicate the potential treat of human infection when water supplies have been polluted by excreta from diseased animals.

Other water-borne pathogenic organisms include protozoa, such as Entamoeba histolytica, the causative organism of amoebic dysentery; viruses, such as the Coxsackie viruses which are closely related to the

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[1]Heeren, R. H., State Department of Health, Des Moines, Iowa. Information on typhoid fever and infectious hepatitis cases in Iowa. Private communication. 1961.

[2]Herrick, J. B., Curtiss Hall, Iowa State University of Science and Technology, Ames, Iowa. Information on brucellosis cases in Iowa. Private communication. 1961.

[3]Tjalma, R. A., University Hospital, State University of Iowa, Iowa City, Iowa. Information on leptospirosis outbreak. Private communication. 1959.

poliomyelitis viruses; and parasitic worms, such as the cercaria, the free-swimming larval stage of organisms in the family Schistosomatidae (3).

All water-borne pathogens must be considered when standards are established for water treatment so that the water may be acceptable from the public health standpoint. Unfortunately, many pathogens are difficult to isolate and to grow out of their natural environment. Consequently, a harmless bacterium known as *Escherichia coli*, normally present in the intestinal tract of warm-blooded animals, is usually used as a test organism to indicate the presence of excreta in water supplies since it is relatively easy to isolate and identify. The present U. S. Public Health Service Drinking Water Standard (68) for a safe water supply is based on the presence or absence of the *E. coli* organism.

In general, studies (12, 79, 83) conducted to determine the comparative resistance of pathogenic bacteria and *E. coli* to chlorine disinfection have indicated that the destruction of *E. coli* was a good index of chlorination effectiveness against bacteria. However, other investigations showed that *E. coli* had a markedly lower resistance to chlorine disinfection than some pathogenic bacteria (54).

Results of recent studies (18, 51, 59, 84), particularly those pertaining to the inactivation of pathogenic viruses, indicate that the *E. coli* index for water purity and normal chlorination procedure for the disinfection of small water supplies are inadequate to assure a safe water supply. Higher chlorine residuals are generally required to destroy viral pathogens, such as the hepatitis, Coxsackie and poliomyelitis viruses, than to destroy bacterial pathogens.

Similarly, higher chlorine residuals are frequently required to destroy milk-spoilage and food-spoilage organisms than the amount usually specified for water to satisfy the drinking water standard as specified by the Public Health Service (8, 17, 19, 54). Unfortunately, inadequate attention has been given to the economic significance of milk-spoilage and food-spoilage bacteria in private water supplies, including both wells and ponds. These bacteria materially affect the quality, nutritive value and permissible storage life of frozen foods and dairy products (9, 15, 20, 47, 66, 73, 77). Bacterial genera such as Bacillus, Pseudomonas, Proteus, Aerobacter, Achromobacter, Alcaligenes, Flavobacterium and Micrococcus are frequently found in frozen foods or dairy products. In general, these genera are common soil-borne and water-borne organisms. Such organisms may be introduced into milk from equipment which has been washed in contaminated water. These organisms may then cause putrefaction or other defects in the food product. High counts of bacteria in milk are undesirable and lower the market quality of the product. Frozen foods, washed before packaging, have their flora increased by the use of contaminated water. These organisms may later cause decomposition of the food even at temperatures below the freezing point. It is highly desirable to remove as many of the organisms as possible from a water supply.

Disinfection by Chlorination

In municipal water treatment practice, it is customary to maintain a chlorine residual in the treated water of 0.2 to 1.0 mg/l provided the contact period is at least 30 minutes before the water reaches the consumer (3). This is the criteria followed in normal chlorination for water disinfection. Similar recommendations with respect to chlorine dosage and contact time for the disinfection of small water supplies can be found throughout existing literature (11, 44, 48, 53, 62, 76).

In contrast to normal chlorination, superchlorination is the application of a greater amount of chlorine to maintain a minimum free chlorine residual at a level considerably higher than that usually maintained in normal chlorination. The idea of superchlorination is not new. However, superchlorination has not been commonly applied in municipal water disinfection practice because of the increased cost of extra chlorine for superchlorination and for chemicals or activated carbon for the dechlorination process to remove the excess chlorine following disinfection. Due to the small volume of water treated from a small water supply, such as a pond water supply for an individual home, this cost limitation is not as applicable. The additional chlorine required within a year's time for the superchlorination of a household water supply would amount to only a few gallons of bleach. Only the drinking and culinary water is dechlorinated in normal practice by passing the water through an activated carbon filter.

Merits of the superchlorination-dechlorination treatment method

A recommendation of superchlorination-dechlorination for small water supplies was made by Willrich and Baumann (87) for the following reasons:

1. to supply a superior water from polluted sources by destroying water-borne pathogens and food-spoilage and milk-spoilage organisms which are not killed by normal chlorination,

2. to compensate for the lack of control over widely varying factors which influence the effectiveness of chlorine disinfection,
3. to compensate for the lack of experienced supervision and timely maintenance of water treatment and disinfection equipment,
4. to decrease the required chlorine contact time and correspondingly reduce the necessary volume and cost of detention storage, and
5. to supply palatable drinking and culinary water by removing undesirable tastes and odors as well as the excess chlorine by carbon filtration.

A Comparison of Water Disinfection Methods

Chlorination

Chlorination is used more frequently for the disinfection of private and public water supplies than any other disinfection method. Chlorine is effective, reasonably economical, and safe to handle and consume as generally used. However, chlorine is not the perfect agent for pond water disinfection. Its effectiveness is influenced by various physical and chemical properties of the water such as low water temperature, high suspended solids content and high pH (87). Chlorine may also add a distinctive taste and odor to the treated water. However, this is not necessarily a disadvantage, but may be an advantage. Any additional taste and odor contributed by the residual chlorine serve the useful purpose of partially masking tastes and odors which occur naturally in pond water. If carbon filtration is desirable to remove naturally occurring tastes and odors from pond water, the chlorine taste and odor are readily removed by the same carbon filtration (31).

Chlorination and all other methods of disinfection are subject to mechanical failure and human error (72). However, only chlorination provides a qualitative nasal test for quickly determining the continuity of the disinfection process.

Chlorination equipment suitable for the treatment of individual water supplies is readily available. Sources of chlorine, particularly in the most convenient solution form as sodium hypochlorite or common laundry bleach, are easily obtained.

Other disinfection methods

Other disinfection methods include the use of bromine, iodine, silver and other oligodynamic metals, ozone, ultraviolet radiation and heat.

Comparing chlorine to the other halogens, Chambers (16) indicated that neither bromine nor iodine have any major advantages. In addition, before iodine can be considered for universal water disinfection, its levels for human ingestion without physiological complications must be more fully understood. Both bromine and iodine are more costly per unit of germicidal effectiveness than chlorine.

Silver has been used in water treatment for many centuries (4). Unlike chlorine, it does not cause a change in water color, taste or odor. Like chlorination, silver treatment can contribute a residual germicidal effect which may last for many days, and its effectiveness is decreased by low temperatures, by some dissolved minerals and by a high pH (16). A major disadvantage of silver treatment is the lack of a simple test for determining adequacy of treatment. Silver concentrations usually used for water disinfection are in the range of 25 to 70 ppb. This upper limit exceeds the maximum silver concentration of 50 ppb now being considered for the revised Public Health Service Drinking Water Standards (16).

Ozone treatment not only disinfects but also removes odors, tastes and color by oxidation, and contributes no taste and odor of its own. However, it leaves no residual germicidal effect to safeguard against post-contamination; it provides no simple test for determining the adequacy of treatment; and a complicated apparatus is required for the disinfection process (3).

Ultraviolet radiation has been suggested for pond water treatment (75). Ultraviolet treatment adds no taste or odor to the water, but its effectiveness is materially influenced by the color, temperature, turbidity and organic matter content of the water to be treated (21, 29, 75). The gradual deposition of suspended matter on the tubes, even from clear water of less than 1 unit of turbidity and 5 units of color, makes it essential that the tubes be kept clean if maximum bactericidal efficiency is to be obtained (29). Additional major disadvantages include the lack of a residual germicidal effect and a simple test for determining adequacy of treatment.

Heat treatment does not affect and is not affected by the physical and chemical properties of the water. Water pasteurization, however, provides no germicidal residual and does not provide a simple test for determining the adequacy of treatment (30).

Summary

1. Silver, ozone, ultraviolet light and heat treatment methods add no taste and odor to the water; chlorine does add taste and odor which can be used as a qualitative nasal test for determining the continuity of treatment.

2. Silver, ozone, ultraviolet light and heat treatment methods provide no simple test for determining the adequacy of treatment; adequacy of chlorine residual can be determined by a simple orthotolidine test.

3. Ozone, ultraviolet light and heat treatment methods provide no residual germicidal effect; chlorine and silver treatment methods do provide a safeguard against post-contamination. However, the required concentration of silver for adequate treatment may exceed the desirable limit for silver in drinking water.

4. Existing knowledge concerning the destruction of viral pathogens as well as bacterial pathogens is more extensive for chlorine disinfection than for any other disinfection method.

5. Chlorination equipment and sources of chlorine are readily available.

6. Chlorination is the least expensive method for water disinfection.

History of Water Treatment

Since natural water varies in quality and frequently contains undesirable materials, it is logical to assume that man has had some knowledge of water variation and treatment since the time of creation.

Moses commented in the Bible about sweetening the bitter waters at Marah. Baker (4) quoted from a collection of medical lore which was thought to date from 2000 B.C.

> "It is good to keep water in copper vessels, to expose it to sunlight, and filter through charcoal.
>
> Impure water should be purified by being boiled over a fire, or being heated in the sun, or by dipping a heated iron into it, or it may be purified by filtration through sand and coarse gravel and then allowed to cool."

From this information, it is apparent that man had an early, practical knowledge of water filtration, disinfection and the removal of undesirable tastes and odors.

Water filtration

Baker's treatise (4) records the history of water filtration from ancient to modern time. Removal of suspended solids by slow sand filtration was used extensively in Europe for many centuries prior to its introduction into the United States in 1832. Following introduction, slow sand filters never became popular. Baker could find a record of only 51 slow sand filters which were built in the United States and Canada prior to 1893. It is interesting to note that three of these 51 filters were constructed in Iowa. One was constructed at Clinton in 1874, one at Marshalltown in 1876 and another at Burlington in 1878.

With the introduction of the rapid sand filter around 1900, relatively few slow sand filters were constructed and many existing slow sand filters were abandoned. In 1940, about 100 slow sand filtration plants were in operation as compared with 2,275 rapid sand filtration plants (4). Consequently, little experimentation with slow sand filters for the treatment of municipal water supplies has been conducted since 1900.

In contrast, slow sand filtration has received primary emphasis in the treatment of surface water for rural use because of its apparent advantages for this application. In comparing the slow sand and rapid sand filters, Babbitt and Doland (3) state "that the slow sand filter is less likely to go wrong under inexperienced operation; it does not require such skilled attendance; the amount of head consumed is less; and it is preferred by some because of the greater reliability of the removal of bacteria; the operating costs may be less per unit volume of water treated; and it is best adapted to waters low in color, turbidity and bacterial count. Among the features of rapid sand filters that make them more desirable than slow sand filters may be included lower first cost; smaller area of land required; the effluent is clear, has less color, and is sparkling; a smaller amount of sand is required for construction; the method of cleaning leaves the filter out of service for a few minutes only; treatment can be more quickly adjusted to variations in raw-water quality; and, finally, the capitalized cost of the plant is less." Slow sand filtration has been recommended for rural water treatment primarily because it requires less attention and operator experience.

Types of filters which have been recommended or investigated in the past 20 years may be grouped and described as follows:

1. Slow sand filters (less than 150 gallons per day per square foot of surface area)

   a. horizontal, gravity flow, sand-filled trench filter

b. vertical, gravity flow, sand-filled box filter

c. gravity flow, sand filter bed

2. Rapid sand filters (more than 1 gallon per minute per square foot of surface area)

a. vertical, gravity flow, sand-filled box filter

b. pressurized, sand-filled tank filter

3. Other granular media filters, either gravity flow or pressurized, which include the

a. anthrafilt filter

b. diatomite precoat filter

c. carbon or charcoal filter

4. Consolidated, porous media filters, either gravity flow or pressurized, such as

a. ceramic, carborundum and concrete filters

b. cellulose and other natural fiber filters

c. fiberglass and other synthetic fiber filters

Horizontal trench filter applications

The horizontal, sand-filled trench filter, connecting the pond and a well beside the pond, might be considered as an adaptation of the "Indian well". The Indians frequently depended on the percolation of turbid water through naturally occurring porous media adjacent to a stream or lake to remove suspended solids from the water.

Many horizontal trench filters were constructed in the Midwest and Plains states as a result of wide dissemination of a 1940 U.S.D.A. publication (36) through the state agricultural extension services. This publication included recommendations for a sand and gravel-filled trench approximately 2 to 3 feet wide, 2 to 3 feet deep and at least 25 feet long. The publication stated that the water could be used for household washing, but that it should not be used for cooking or drinking without disinfection. Generally, the recommendation for water disinfection has not been followed. A 1954 report from Clark[1] indicated that over 1,000 horizontal sand-filled trench filters had been constructed in Missouri and that about one-third of the farm families were drinking the filtered water without chlorination or other means of disinfection.

Vertical filters for the treatment of rural water supplies

Recommendations for the construction and operation of a rather elaborate vertical, slow sand filter were published by the Portland, Oregon office of the Farm Security Agency (27) about 1940. The date of publication is indefinite, but since the Farm Security Agency was succeeded by the Farmers Home Administration in 1946, it is apparent that this was one of the earliest publications concerning the filtration of surface water for rural use. The principal application of this filter was to remove suspended solids from irrigation ditch water. The recommendations essentially paralleled accepted slow sand filtration practice for municipal water treatment. Because of its complexity and high construction cost, the unit was not widely used.[2]

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[1]Clark, M. W., Agricultural Engineering Department, University of Missouri, Columbia, Missouri. Information on pond water treatment. Private communication. 1954.

[2]Huber, M. G., Agricultural Engineering Department, Oregon State College, Corvallis, Oregon. Information on filters. Private communication. 1954.

More recent Oregon publications by the Agricultural Extension Service (46) in 1951 and the Oregon State Department of Health (64) in 1952 describe more practical units for the clarification of irrigation ditch water. The Department of Health publication described what might be considered today as the conventional, 50 gallons per day per square foot, slow sand filter. The Extension Service publication described a unique, gravity flow, 3-1/3 gallons per minute per square foot, rapid sand filter. This filter, consisting of 6 inches of clean pumice sand supported by carborundum underdrain plates, could be cleaned by back-washing or by removing 2 or 3 inches of the pumice sand and replacing it with new sand. Under the most extreme conditions usually encountered with irrigation ditch and mountain stream water of relatively low turbidity, Huber[1] reported that a filter run of 4,000 gallons per square foot of surface area could be expected.

Other publications concerning the use of rapid sand filters for the treatment of low turbidity irrigation ditch and lake water were published by the Departments of Health in Utah (81) and Minnesota (58). The Utah publication described a gravity flow, rapid sand filter and the Minnesota publication described a pressurized, rapid sand filter.

Pond water treatment investigations in Texas prior to 1955

One of the first bulletins concerning pond water treatment was prepared by Winston (88) in 1945. He described a vertical, gravity flow, slow sand filter which had a recommended filtration rate of 50

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[1]Huber, M. G., Agricultural Engineering Department, Oregon State College, Corvallis, Oregon. Information on filters. Private communication. 1954.

gallons per day per square foot of surface area. This filter was tested more thoroughly by Sorrels and Zeller (74) in 1952. It proved effective in removing suspended solids from the water, but bacteria were not completely removed. Chlorination to a residual of 0.4 mg/l was recommended. In 1954, Sorrels and Zeller (75) reported on their use of ultraviolet light for pond water disinfection. They found that ultraviolet radiation would disinfect the slow sand filter effluent so that it would meet the U. S. Public Health Service requirements for bacteriological quality. They also pointed out the major limitations of ultraviolet light for pond water disinfection. Suspended solids coated the lamps and reduced their effectiveness, and there was no simple test to determine adequacy of treatment. The same investigators recommended chlorine disinfection in a later publication (76) and ultraviolet light was not mentioned.

Pond water treatment investigations in Oklahoma prior to 1955

Daniel (22) expanded on the basic information supplied by Winston (88) concerning the use of a gravity flow, slow sand filter. He incorporated provisions for coagulation and sedimentation prior to filtration, for an adjustable rate-of-flow controller and for a float-suspended inlet to remove water near the pond surface. Initially using a filtration rate of 50 gallons per day per square foot, he found that as much as 3,500 gallons of filtrate per square foot of filter surface could be expected between filter cleanings under the best conditions. When the water was not well flocculated, as little as 500 gallons per square foot was obtained. Daniel later reported[1] that the length of

[1] Daniel, E. R., Agricultural Engineering Department, Oklahoma State University, Stillwater, Oklahoma. Information on pond water treatment. Private communication. 1954.

run could be increased about five times by reducing the filtering rate to 25 gallons per day per square foot. This rate was recommended for highly turbid water by Phagan and Daniel (67) in their 1954 publication.

Daniel (22) also described two other types of gravity flow filters in addition to the vertical, slow sand filter. One consisted of a sand filter bed in the side of the pond. His recommendations concerning the use of a sand filter bed included provisions for small batch clarification of the pond water in a small pond below the major storage reservoir, and for the cleaning of the filter bed by dewatering the small pond. The horizontal, sand-filled trench filter was also described. He emphasized the difficulty encountered in cleaning the submerged filter entrance and the higher taste and odor level when water was removed from near the bottom of the pond.

Pond water treatment investigations in Missouri prior to 1955

Due to the increased use of pond water in Missouri, Temple (78) initiated a study in 1950 concerning the properties of pond water and the effectiveness of a vertical, gravity flow, slow sand filter. He reported that the filter would effectively reduce turbidity to an acceptable level but that chlorination was essential to make the water safe according to accepted standards.

In 1953, Shanklin (71) reported on a more thorough investigation of Missouri pond water quality before and after filtration through a sand-filled trench filter. After studying 30 existing filter installations, he concluded that the filtered water would not consistently satisfy the U. S. Public Health Service requirements for bacteriological quality without disinfection and that there was no functional requirement for a sand-filled trench to be longer than 5 feet.

Guyer (32) reported on experimentally-controlled, vertical and horizontal, gravity flow, slow sand filters in 1954. He observed that the two filters were about equally effective in bacterial and turbidity reduction. In horizontal filtration, 3-1/2 feet of sand were as effective in reducing bacterial count as 18 feet of sand. Comparing sand and anthrafilt as porous media for slow sand filters, Guyer (32) reported that eight times as much water could be filtered through the anthrafilt as for sand with the same resulting head loss. He also concluded that disinfection was essential to produce a bacteriologically safe water. None of the tested slow sand filters consistently produced a safe water. Turbidity was effectively reduced at a flow rate of approximately 70 gallons per day per square foot of filter surface area.

The results of these three studies at the University of Missouri were summarized and published in 1955 as a research bulletin (25) and in 1957 as a popular publication (44). The latter included recommended construction and operation procedures for a vertical, gravity flow, slow sand filter, and the procedure for chlorine disinfection. Construction details for a coagulation-sedimentation chamber were not included since a preference for gypsum treatment within the pond was indicated if the water turbidity exceeded 25 units.

Pond water use and investigations in Iowa

Iowa farmers have been constructing farm ponds for many years. The first extensive demand for farm ponds began in the drought years of 1894 and 1895. In the early 1930's, the federal Civilian Conservation Corps assisted in constructing many ponds throughout the state. The success of these ponds through the drought years of 1933 and 1934, proved the value of ponds as the source of farm water supply.

The dry years in the early 1950's again caused an increased interest in pond water use. Many inquiries requesting information on pond water treatment for domestic use were received by the Iowa Agricultural Extension Service. To evaluate the extent of the problem and the need for information on pond water treatment, a survey questionnaire was sent to county extension directors. The locations of 29 homes where pond water was being used for domestic purposes were obtained through this survey. Twenty of these installations were visited to observe the treatment systems and to interview the owners.

Assistance in installing new treatment systems was provided to numerous pond owners. Selected new and existing systems were included in a preliminary sampling and testing program which was initiated in 1954.

Information obtained from these preliminary investigations were reported (6, 85, 86) and evaluated. Based on the evaluation and resulting conclusions from the preliminary studies, more intensive investigations were initiated on small segments of the total pond water treatment problem. The results of several of these investigations concerning chlorination, detention tanks and carbon filtration have been reported in M. S. theses by Varma (82), Ludwig (57) and Guillaume (31).

Investigations in other states in the past 3 years

Prior to 1958, all known research on pond water treatment for domestic use had been conducted in Texas, Oklahoma, Missouri and Iowa. Since the prolonged drought conditions of the 1950's were affecting ground water supplies over a more extensive area of the mid-continent, information on pond water treatment was in increasingly greater demand, and investigators in other states initiated studies.

Since 1958, research results on pond water treatment have been released by investigators in Indiana (2, 52), Ohio (30, 39, 40, 41, 42), Tennessee (34, 35), and Arkansas (38). Also, studies were continued in Missouri (43, 45) and Oklahoma (21, 23), as well as in Iowa (7, 87).

To date, state university or department of health publications concerning pond water treatment for domestic use have been published in Kansas (55, 56), Kentucky (11), Ohio (62), Indiana (53), Illinois (48), Oklahoma (63, 67), Texas (76) and Missouri (44).

PROCEDURES

A preliminary pond water study was initiated in 1954 and was followed by more intensive investigations in 1958 and 1959 to define the broad problem area of pond water treatment in Iowa, to identify qualitative and quantitative properties of pond water as it occurred naturally or was modified by treatment, and to determine the effectiveness of pond water treatment methods and equipment.

General Procedure

The general procedure for this study consisted of several parts:

1. A survey questionnaire was sent to county extension directors to obtain the location of ponds where water was being used for domestic purposes.

2. A survey questionnaire was sent to consumers of pond water to obtain descriptive physical data concerning their treatment systems.

3. Inspection trips were made to observe these installations and to obtain additional information through personal interviews.

4. Random samplings and analyses of water from numerous pond water systems were made to gain preliminary information as to the range in values of water properties which might be anticipated and encountered in a more intensive testing program to follow.

5. Field installations were selected for intensive observation, sampling and analysis.

6. Results obtained from the field installations were evaluated and controlled laboratory experiments were initiated on selected segments

of the total treatment problem.

Sampling and Analytical Procedures

Water samples were collected at pertinent and available points of access in each treatment system to measure the effect on water properties of the various components in the system.

Pond water samples were taken approximately 6 feet from the shoreline and 6 inches below the water surface. Additional sampling points in the major field installations are identified in a following section concerning the description of these installations.

In general, samples were collected in clean glass bottles or jugs. They were transported a distance of 50 to 70 miles to the Iowa State University laboratories for analysis. Water samples were chilled as necessary to limit changes in water properties during transport.

Physical and chemical analyses

Apparent color was determined without centrifugation or filtration by the use of Nessler tubes as described in Standard Methods (1).

Turbidity was determined in 1954-55 by use of the Jackson candle turbidimeter as described in Standard Methods and in 1958-59 by use of the Bausch and Lomb Spectronic 20 colorimeter as described by Hach (33).

The glass electrode method as described in Standard Methods was used to determine pH in 1954-55. In 1958-59, pH was determined by use of a Hellige portable colorimetric test kit.

Total hardness was determined by the EDTA titration method as described in Standard Methods.

Total alkalinity was determined by the titration method as described in Standard Methods.

Nitrate as nitrate nitrogen was determined by use of the Brucine method as described by Hach (33).

Iron was determined by use of a Hach portable colorimetric test kit.

Chlorine residual was determined by use of the orthotolidine method with a Hellige portable colorimetric test kit.

Bacteriological analyses

A number of different media for bacteriological tests were used in 1954-55. Normally, each water sample was plated on three or more of the following media:

1. nutrient agar
2. tryptone-glucose extract
3. gelatin
4. eosin-methylene blue agar
5. desoxycholate lactose agar
6. tryptone-glucose extract milk agar

The tests were conducted according to Standard Methods with a few exceptions. Total counts were made with the aid of a Quebec colony counter. Plates containing from 30 to 300 colonies were preferred in reporting plate counts. All reported counts were an average of four similar plates.

In 1958-59, the membrane filter method was used for making bacteriological analyses. Equipment provided with an Isopor Water Laboratory was used in the bacteriology laboratory except that metal ointment tins were used instead of glass or plastic petri dishes. MHD Endo broth media was used for coliform determinations by the direct membrane filter test. Incubation time was 18 ± 1 hours at 37° C. Coliform colonies were counted using a low power microscope. Plates containing from 20 to 60 colonies were preferred in reporting plate counts. Verification tests were made occasionally to prove the identity of colonies indicated as coliforms.

DESCRIPTION OF MAJOR FIELD INSTALLATIONS

Twenty pond water treatment systems were observed and tested during the preliminary phase of this investigation. However, due to personnel and monetary limitations, it was necessary to confine the intensive testing program to a smaller number of installations.

Various factors were considered in the selection of the major field installations. These were the age and size of pond, type and size of watershed, type of components in the treatment system, cooperativeness of the pond owner and location of precipitation recorder stations.

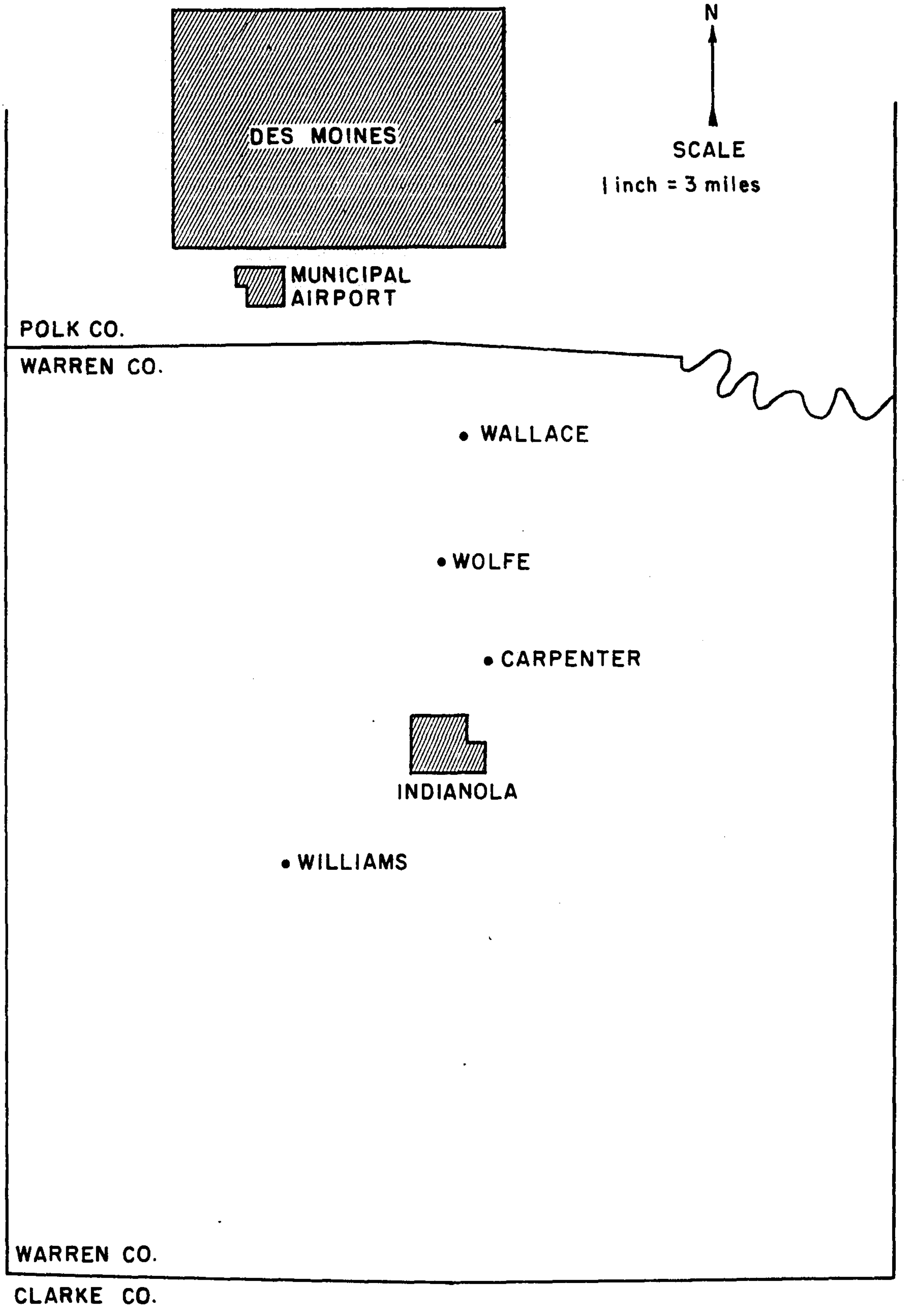
As indicated in Figure 3, Des Moines is on the northern boundary of the major pond construction area in Iowa. Ames and Iowa State University are located 35 miles north of Des Moines. It was, therefore, more convenient to select field installations near Des Moines.

Another factor of importance was the location of precipitation recorder stations at the Des Moines Municipal Airport and in Indianola. Figure 4 shows the locations of the four selected field installations with respect to Des Moines and Indianola.

The Carpenter and Williams installations were observed and tested during the 1954-55 exploratory period. The Wallace and Wolfe installations were added during the more intensive testing period of 1958-59.

Observation and testing of these four installations permitted an evaluation of four different types of primary filters: the vertical, gravity flow, slow sand filter; the buried collector tile under the pond; the trench filter connecting the pond and a well beside the pond; and the filter bed in the side of the pond. Secondary filters in these

Figure 4. Locations of the major field installations with respect to Des Moines and Indianola.


DES MOINES
N
SCALE
1 inch = 3 miles
MUNICIPAL AIRPORT
POLK CO.
WARREN CO.
WALLACE
WOLFE
CARPENTER
INDIANOLA
WILLIAMS
WARREN CO.
CLARKE CO.

installations included a rapid sand pressure filter, a granular carbon filter and a precoat carbon filter. Disinfection methods used in these installations included superchlorination, normal chlorination and heat treatment.

The installations varied in pond age and size. Watershed size, cover and treatment differed in various degrees. Table 1 contains pertinent descriptive information concerning the four major field installations.

Carpenter Pond Installation

The Carpenter pond, constructed in the late fall of 1953, partially filled with water in the spring of 1954. Since a conventional, perforated barrel inlet had already been installed in the pond, a slow sand filter, clear well and insulated pumphouse were designed and installed below the pond in June 1954, Figure 5. The construction plans for the filter and clear well are shown in Figure 6.

The original filter was designed with 60 square feet of surface area since the maximum daily water demand was estimated to be 3,000 gallons. However, provisions were included for future filter expansion if this demand should be exceeded or if a filtering rate less than 50 gallons per day per square foot was desired. Approximately 1 foot of pea gravel was placed over the underdrain. The 3 feet of filter sand had an effective size of 0.28 millimeters and a uniformity coefficient of 2.32.

The small clear well was installed with the intention of pumping from the clear well to an existing 7,000-gallon storage tank at the

Table 1. Description of field installations

	Pond installation			
	Carpenter	Williams	Wallace	Wolfe
Year constructed	1953	1950	1956	1954
Pond size, acres	1.5	1.0	0.5	0.2
Pond depth, feet	15	15	15	8
Watershed-to-pond-size ratio	10:1	10:1	60:1	10:1
Watershed cover and use	80% cultivated, 20% meadow in 1954-55 and in 1958-59	30% cultivated, 70% pasture in 1954-55; 100% pasture in 1958-59	50% cultivated, 50% meadow and pasture	100% meadow
Cover around pond site	bare to poor brome-alfalfa in 1954-55; fair to good brome-alfalfa in 1958-59	excellent bluegrass and deciduous trees in 1954-55 and 1958-59	bare to poor grass-legume mixture	excellent grass-legume mixture
Primary filter	vertical, slow sand filter unit below pond	integral buried collector tile	integral trench filter	integral filter bed
Filtering media	fine sand	sand, silt and clay over tile	pea gravel	pea gravel
Secondary filters	none	precoat carbon filter	pressure sand and granular carbon filters	none
Disinfection method	none	super-chlorination	normal chlorination	heat treatment

Table 1. Continued

	Pond installation			
	Carpenter	Williams	Wallace	Wolfe
Water use	livestock	domestic and livestock	domestic	domestic (hot water only)

farmstead. However, this step was not completed and the system was operated throughout the testing period with only the small clear well for filtered water storage. The filtered water was not disinfected since it was used for livestock water only.

Williams Pond Installation

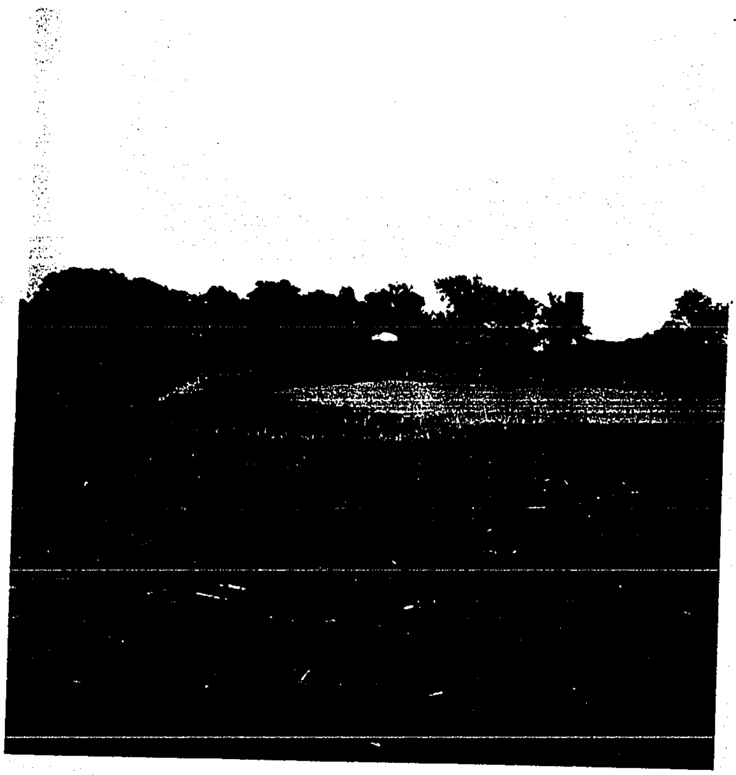
The Williams installation provided an opportunity to study one of the three types of integral filters shown in Figure 7. A buried collector tile already existed in the bottom of the pond. This consisted of 70 feet of 5-inch-diameter field drain tile with a minimum crack opening every 1 foot of length. The collector tile was initially covered with approximately 12 inches of sand and 6 inches of soil.

The Williams pond, constructed in 1950, contrasted with the newly constructed Carpenter pond in that the pond banks and the watershed area in the immediate vicinity of the pond were well protected by an excellent bluegrass and tree cover. As shown in Figure 8, deciduous trees surround the well beside the pond and are adjacent to the shoreline

Figure 5. Carpenter pond installation.

A vertical, slow sand filter unit, located below the pond, supplies filtered water to the farmstead for livestock consumption.

The treatment unit consists of a slow sand filter and clear well. An insulated pump house is located over part of the clear well.



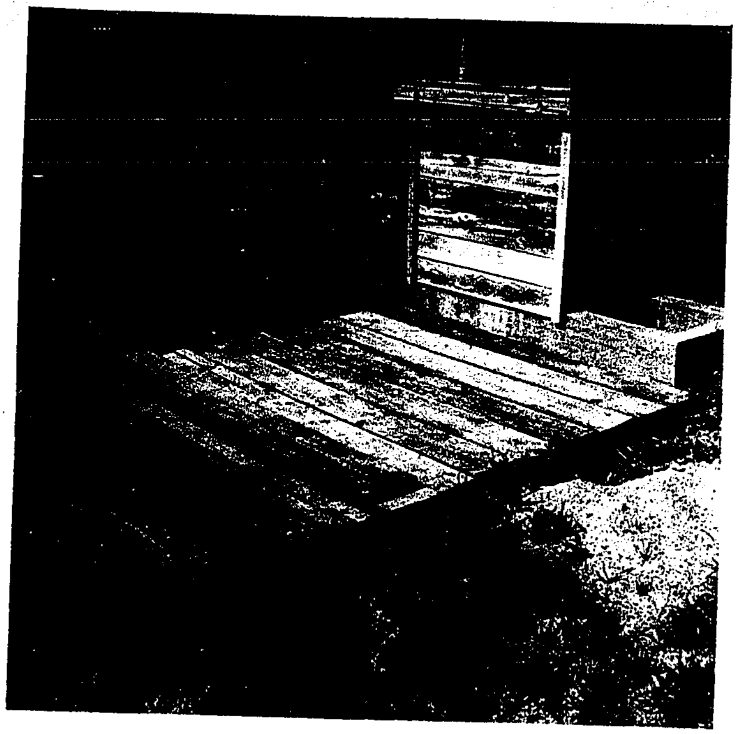
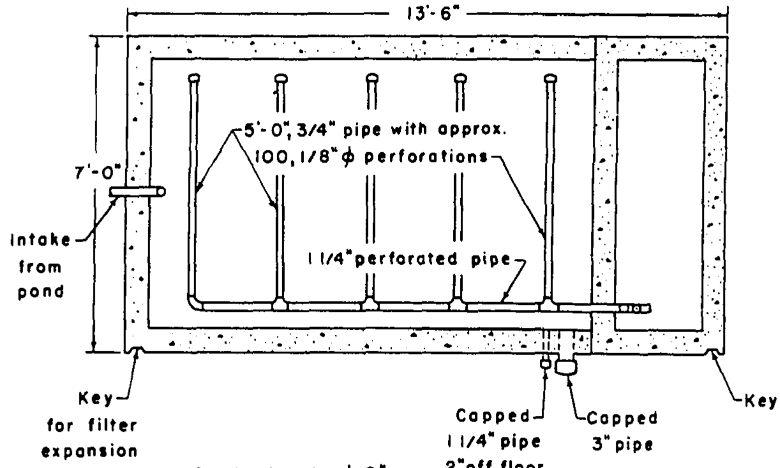
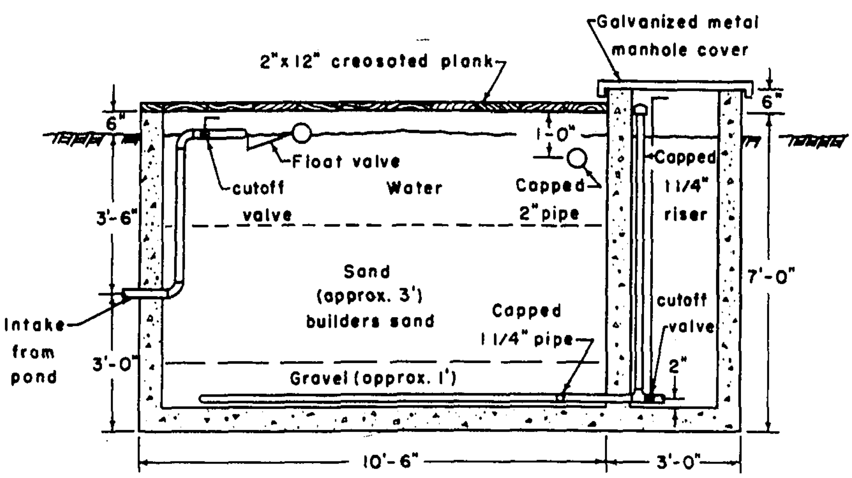


Figure 6. Construction plans for the Carpenter slow sand filter.


13'-6"
7'-0"
5'-0", 3/4" pipe with approx.
100, 1/8"ϕ perforations
1 1/4" perforated pipe
Intake from pond
Key for filter expansion
Capped 1 1/4" pipe 2" off floor
Capped 3" pipe
Key
Scale: ⊢⊣ = 1'-0"


Galvanized metal manhole cover
2"x12" creosoted plank
6"
1'-0"
Float valve
cutoff valve
Water
Capped 2" pipe
Capped 1 1/4" riser
3'-6"
Sand (approx. 3') builders sand
Capped 1 1/4" pipe
cutoff valve
7'-0"
Intake from pond
3'-0"
Gravel (approx. 1')
2"
10'-6"
3'-0"

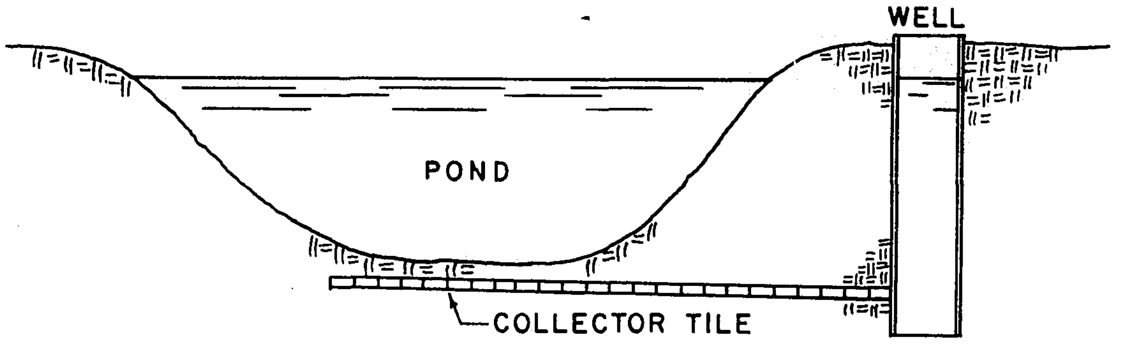
Scale: ⊢⊣ = 1'-0"

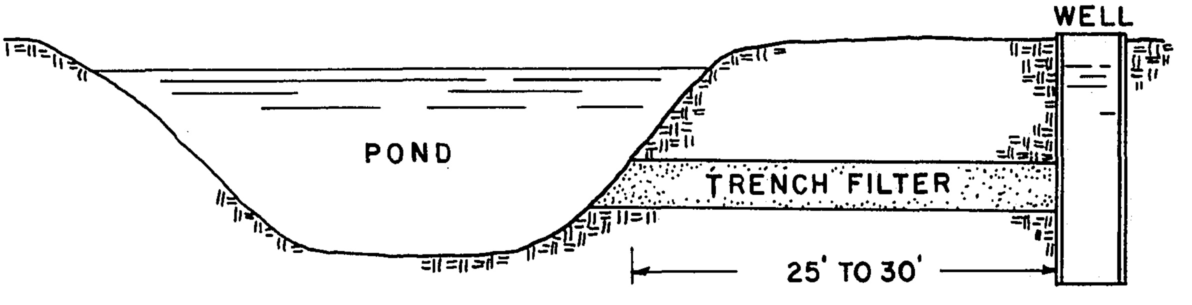
Figure 7. Integral pond water filters.

a. A buried collector tile under the pond which discharges into a well beside the pond.

b. A horizontal, trench filter which connects the pond and a well beside the pond.

c. A filter bed in the side of the pond which connects the pond and a well beside the pond.


WELL
POND
COLLECTOR TILE


WELL
POND
TRENCH FILTER
25' TO 30'

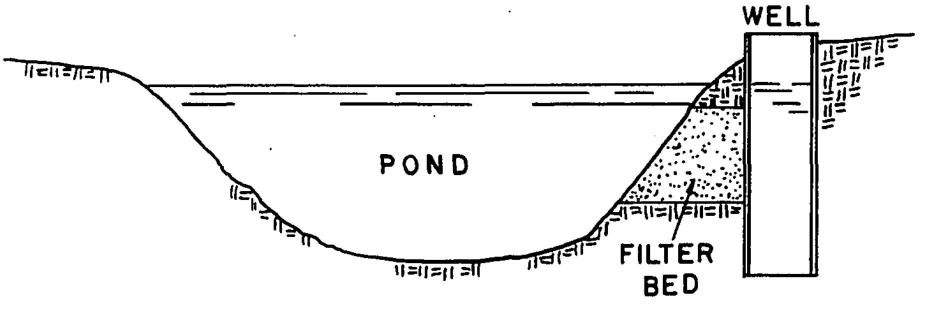

WELL
POND
FILTER
BED

Figure 8. Williams pond installation.

A buried collector tile discharges into the well beside the pond. The filtered water is pumped to the farmstead for livestock and domestic uses.

An excellent bluegrass and deciduous tree cover surrounds the pond.

along one-third of the perimeter of the pond.

In June of 1954, a superchlorination-dechlorination system was installed in the Williams residence, Figures 9 and 10. Chlorine solution was injected on the suction side of the pump as water was withdrawn from the storage reservoir. A 30-gallon pressure tank in use during the 1954-55 testing period was replaced with an 82-gallon pressure tank prior to the 1958-59 testing period. With the pressure system installed in the house basement, the distribution pipes provided a minimum chlorine contact time of less than 1 minute.

Water withdrawn from a special drinking water faucet at the kitchen sink was dechlorinated as it passed through a precoat carbon filter. Water meters were installed to record the consumption of dechlorinated water and total water consumption.

Wallace Pond Installation

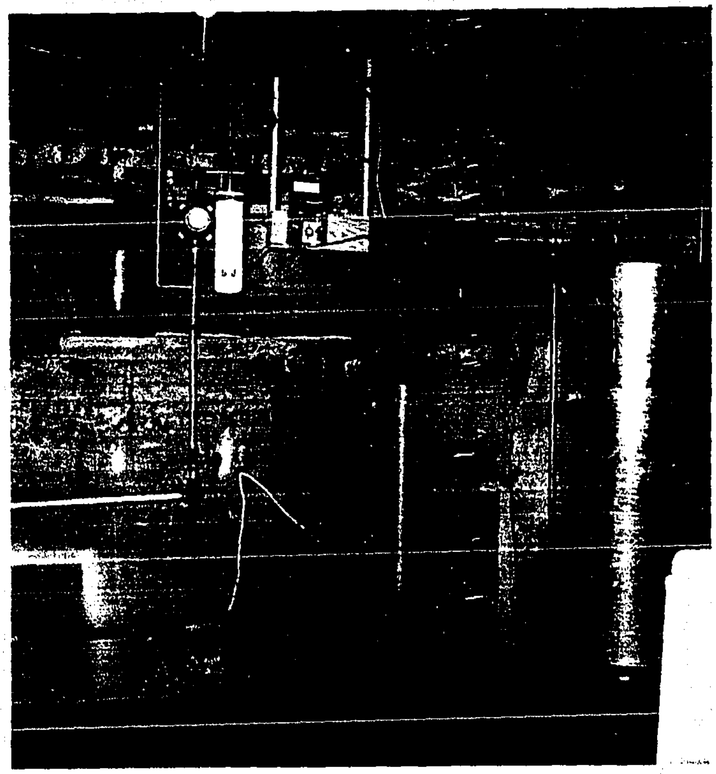
Several water sources were used to supply water to the Wallace home from 1954 through 1959. The pond water supply used during 1954-55 was observed and tested occasionally. This pond failed in 1956 due to inadequate watershed area and runoff. Two shallow wells were installed to replace the original pond source. However, the combined yield of the two wells would not supply the water demand of about 200 gallons per day so a new pond was constructed within 25 feet of the shallow wells. Whereas the watershed-to-pond-size ratio is usually about 10:1 for the Des Moines area, this pond installation has a 60:1 ratio. The pond with drop inlet spillway is shown in Figure 11.

The pond partially filled during the summer and fall of 1956.

Figure 9. Williams superchlorination-dechlorination system.

Water, withdrawn from a storage reservoir, is superchlorinated on the suction side of the pump. Drinking water, as it is withdrawn from the pressure tank, is dechlorinated by the precoat carbon filter.

Water meters were installed to record total water consumption and carbon-filtered water consumption. Carbon filter effluent samples were withdrawn from the special sampling faucet.



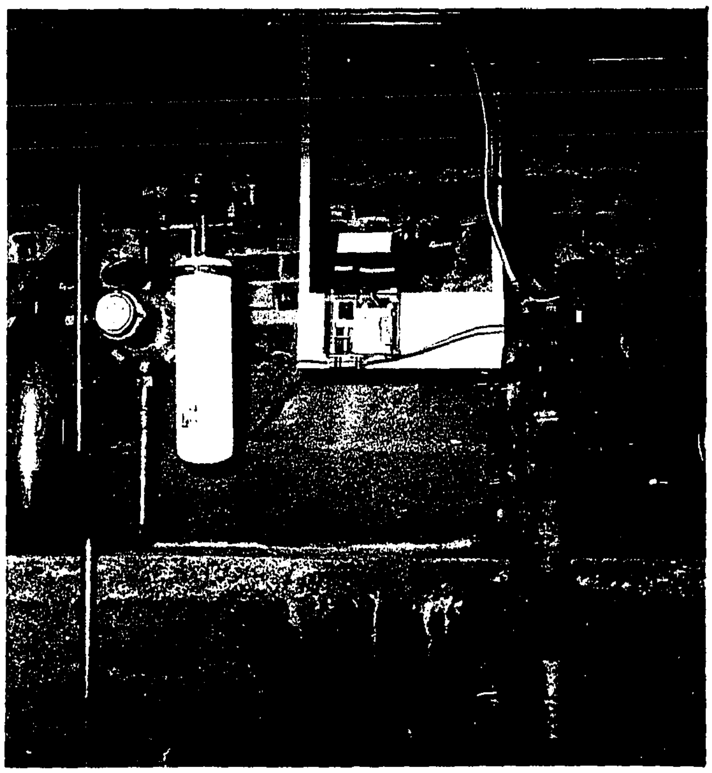


Figure 10. Schematic diagram of a superchlorination-dechlorination test system.

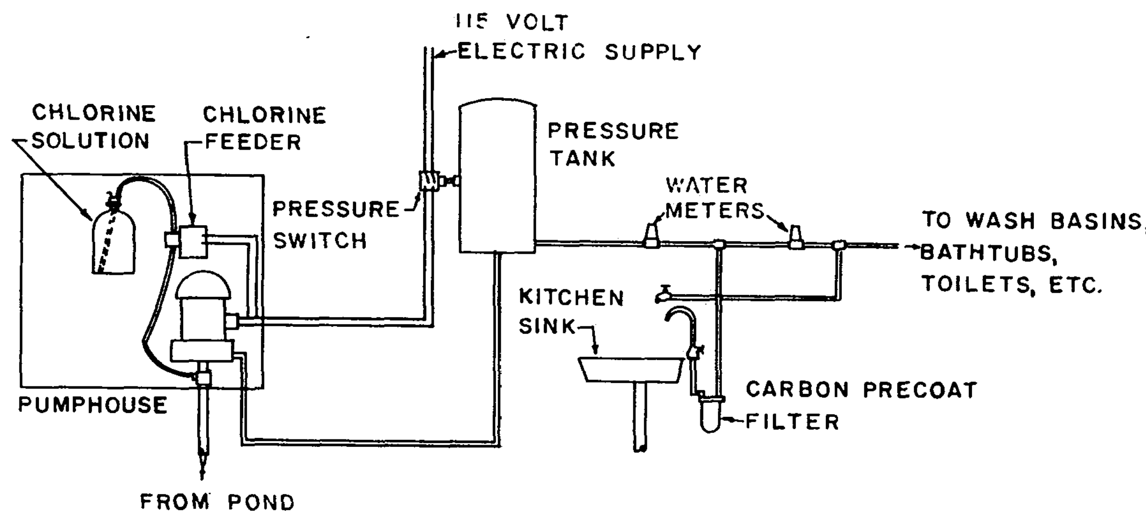
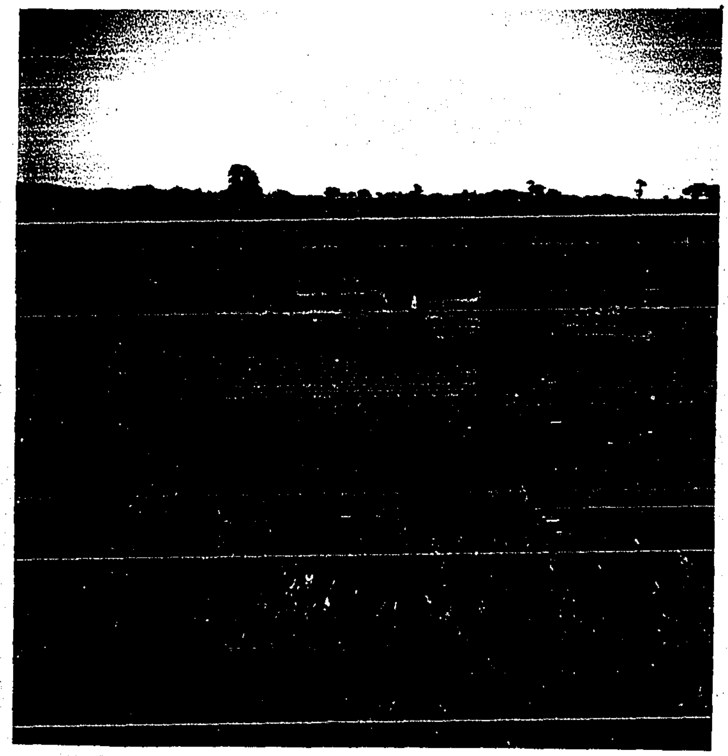

115 VOLT
ELECTRIC SUPPLY
CHLORINE
SOLUTION
CHLORINE
FEEDER
PRESSURE
TANK
WATER
METERS
PRESSURE
SWITCH
TO WASH BASINS,
BATHTUBS,
TOILETS, ETC.
KITCHEN
SINK
PUMPHOUSE
CARBON PRECOAT
FILTER
FROM POND

Figure 11. Wallace pond installations.

The upper pond was in use during the 1954-55 testing period. The lower pond was constructed in 1956 and served as the water source during the 1958-59 testing period.

The lower pond has a surface area of about 1/2 acre and a watershed area of about 30 acres. A large drop inlet spillway is required to discharge the pond water overflow. A pea gravel-filled trench connects the pond and a well beside the pond.



When it appeared evident that the natural percolation rate of water from the pond to the wells was inadequate to satisfy the water demand, a sand-filled trench was installed to connect one of the wells with the pond. Within 6 months, the entrance to the trench filter clogged. The washed builder's sand was then replaced with washed pea gravel in 1957. This was the primary filter in the Wallace installation during the 1958-59 testing period.

The integral trench filter, as diagramed in Figure 7 and as constructed in the Wallace installation, measured about 2 feet wide and 6 feet deep in cross section and 25 feet in minimum length from the shoreline to the well.

The pond water was chlorinated as it was withdrawn from a storage reservoir. The normal chlorination system involved the injection of chlorine solution on the suction side of the pump by a positive displacement solution feeder. The pump, 30-gallon pressure tank and chlorine feeder were housed in a insulated pump pit. An estimated minimum chlorine contact time of 4 minutes was provided by the combined detention in approximately 250 feet of 1-1/4 inch pipe, a 90-gallon storage tank and a 14 inch x 48 inch pressure sand filter. All water used within the home was dechlorinated as it passed through a 14 inch x 48 inch granular carbon filter.

Wolfe Pond Installation

The third type of integral filter, a pea gravel filter bed as diagramed in Figure 7, was installed in the side of the Wolfe pond in 1954. A well with insulated pumphouse was located beside the pond,

Figure 12. The least distance of water travel through the filter bed was about 6 feet, and the surface area of the filter bed was about 36 square feet.

The filtered pond water supplied all hot water requirements in the home. A conventional water heater, located in the house basement, raised the water temperature to a range of 140 to 150° F.

Flow Diagrams and Sampling Points

The flow diagrams and sampling points for the field installations are indicated in the following table.

Table 2. Flow diagrams and sampling points for the field installations

Flow diagram	Sampling points
Carpenter installation	
pond	1. pond surface
↓	
barrel inlet	
↓	
slow sand filter	2. filter inlet valve (barrel inlet effluent and filter influent)
↓	
clear well	3. clear well (filter effluent)

Table 2. Continued

Flow diagram	Sampling points
Williams installation	
pond	1. pond surface
↓	
buried tile collector	
↓	
clear well	
↓	
storage reservoir ←--chlorine injection	2. storage reservoir (tile collector effluent)
↓	
pressure tank (30 or 82 gallons)	3. pressure tank faucet (chlorinated water)
↓	
precoat carbon filter	4. post-carbon sampling faucet (carbon filter effluent; dechlorinated water)
Wallace installation	
pond	1. pond surface
↓	
trench filter	
↓	
clear well ←--chlorine injection	
↓	
pressure tank (30 gallons)	
↓	
150' of 1-1/4" pipe (12 gallons of storage)	
↓	
storage tank (90 gallons)	
↓	
100' of 1-1/4" pipe (8 gallons of storage)	2. hose bib on house foundation (trench filter effluent and rapid sand filter influent; chlorinated water)
↓	
rapid sand filter (14" x 48")	
↓	
granular carbon filter	3. laundry sink faucet (carbon filter effluent; dechlorinated water)

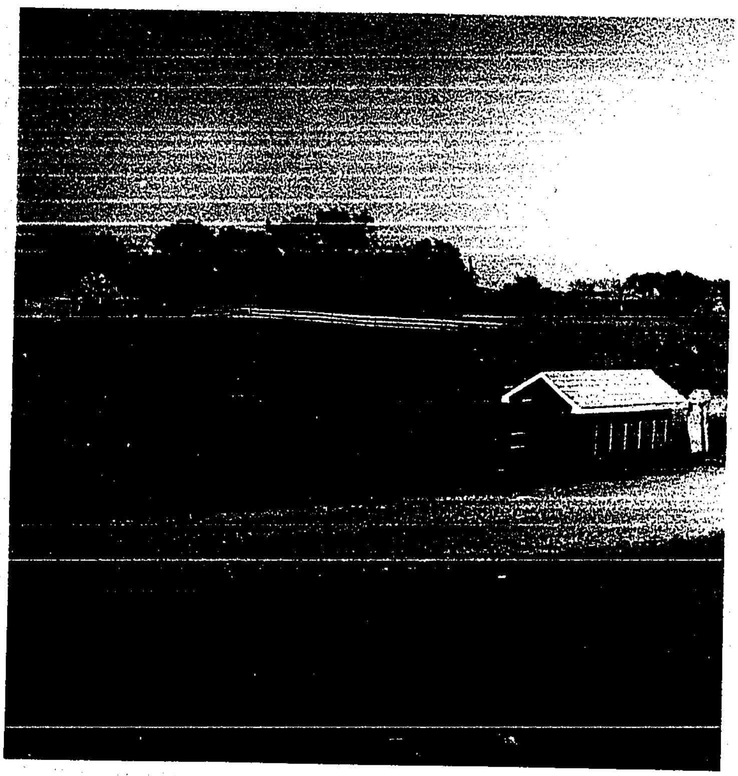
Table 2. Continued

Flow diagram	Sampling points
	Wolfe installation
pond	1. pond surface
↓	
filter bed	
↓	
clear well	
↓	
pressure tank (40 gallons)	
↓	
water heater (40 gallons)	2. laundry sink faucet (filter bed effluent; heated water)

Figure 12. Wolfe pond installation.

An insulated pump house is located over the well beside the pond. A pea gravel filter bed connects the pond and the well.

Filtered pond water is pumped to the house where it is heated to supply all domestic requirements for hot water.



RESULTS, EVALUATION AND CONCLUSIONS

Factors Influencing Water Properties in the Pond

Effect of pond age on apparent color, turbidity and nitrates

Pond age affected several physical and chemical properties of pond water. Apparent color, turbidity and nitrate concentrations were generally higher in new ponds than in old ponds.

Water samples were tested from six ponds in June of 1954 and again in June of 1955. Three of these ponds had been constructed in the late fall of 1953 or early spring of 1954 and were classified as new ponds. The other three ponds had been in existence for several years and were classified as old ponds. Test results for the six ponds are tabulated in Table 3.

A comparison of the 1954 results for all six ponds indicates that the new ponds were higher in apparent color, turbidity and nitrate concentrations than the old ponds. A comparison of the 1955 results with those of 1954 for the three new ponds shows a universal reduction in the concentrations of these three properties with age.

A progressive change in apparent color, turbidity and nitrate concentrations with time for the newly-constructed Carpenter pond is indicated in Figure 13. All three properties continuously decreased in 1954. Following 1954, factors other than pond age had a dominant influence on apparent color and turbidity concentrations, but the nitrate concentration continued to decrease with time throughout 1954 and 1955. During the 1958-59 testing period, the low nitrate concentration in the

Table 3. Apparent color, turbidity and nitrate concentrations in new and old ponds

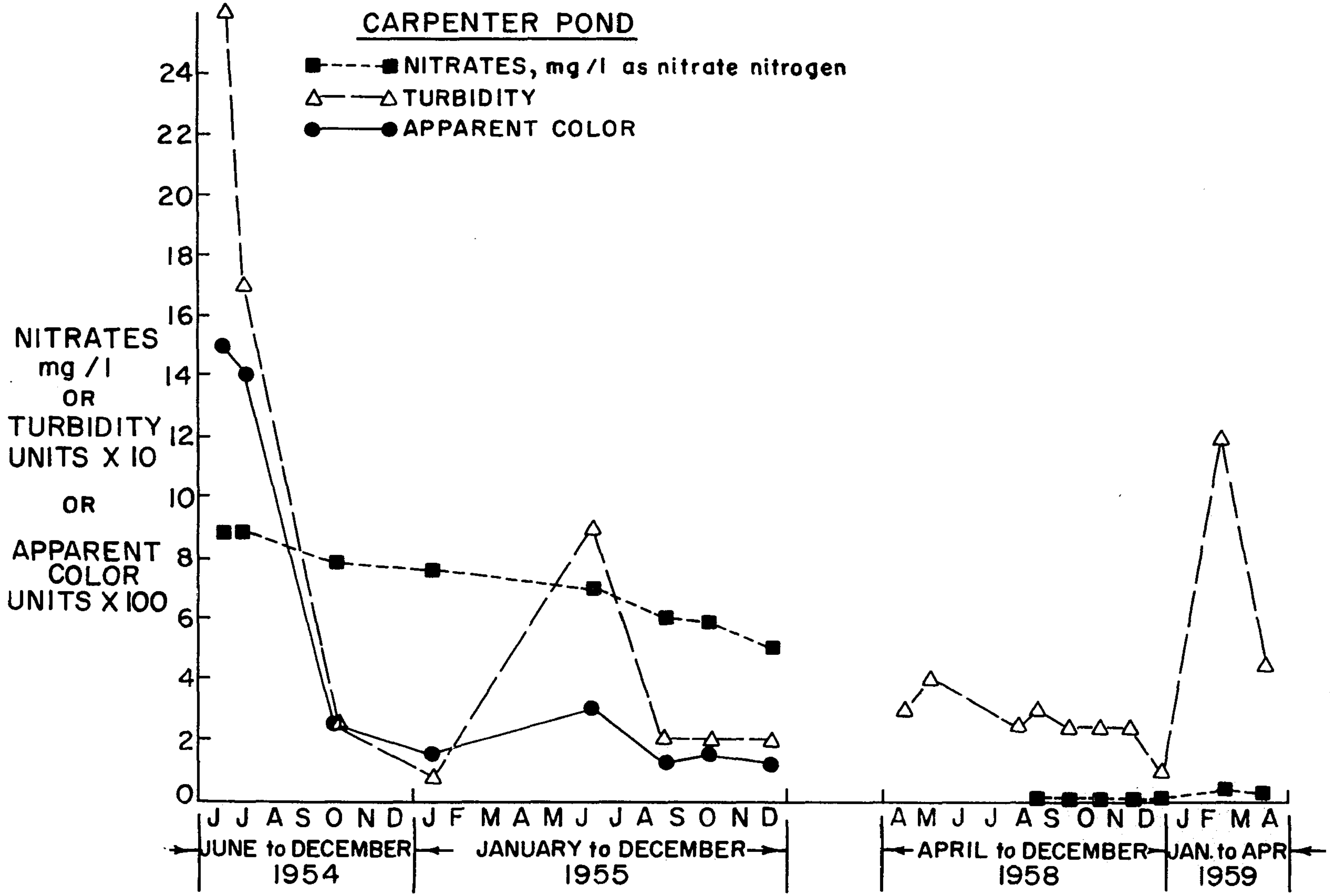
Pond owner	Sampling date	Apparent color units[a]	Turbidity units	Nitrates,[b] mg/l[c]
		New ponds		
Carpenter, George	6-25-54	1500	260	8.8
	6-20-55	300	90	7.0
Wolfe, Robert	6-25-54	1000	190	1.0
	6-20-55	250	80	0.0
Miner, A. L.	6-25-54	100	160	6.1
	6-20-55	25	45	1.1
		Old ponds		
Williams, Luther	6-25-54	25	3	0.0
	6-20-55	10	6	1.5
Wallace, Joe	6-25-54	40	30	0.0
	6-20-55	25	9	0.0
Lazear, G. W.	6-25-54	50	35	---
	6-20-55	40	20	0.0

[a]Color, as reported and used in the discussion, refers to apparent color and not true color.

[b]Nitrates, as reported and used in the discussion, refers to nitrate measured as milligrams per liter of nitrate nitrogen.

[c]mg/l, milligrams per liter, is quantitatively equivalent to ppm, parts per million.

Figure 13. Variations in nitrate, turbidity and apparent color concentrations in the Carpenter pond.


CARPENTER POND
NITRATES, mg /l as nitrate nitrogen
TURBIDITY
APPARENT COLOR
NITRATES mg /l OR TURBIDITY UNITS X 10 OR APPARENT COLOR UNITS X 100
24
22
20
18
16
14
12
10
8
6
4
2
0
J J A S O N D J F M A M J J A S O N D
A M J J A S O N D J F M A
JUNE to DECEMBER 1954
JANUARY to DECEMBER 1955
APRIL to DECEMBER 1958
JAN. to APR 1959

Carpenter pond was characteristic of the nitrate level generally found in older ponds.

In contrast to the newly-constructed Carpenter pond, the older Williams pond consistently tested lower in apparent color and turbidity levels. Values obtained for apparent color and turbidity levels in the Williams pond water are plotted in Figure 14. The nitrate level in the Williams pond always tested less than 0.1 mg/l.

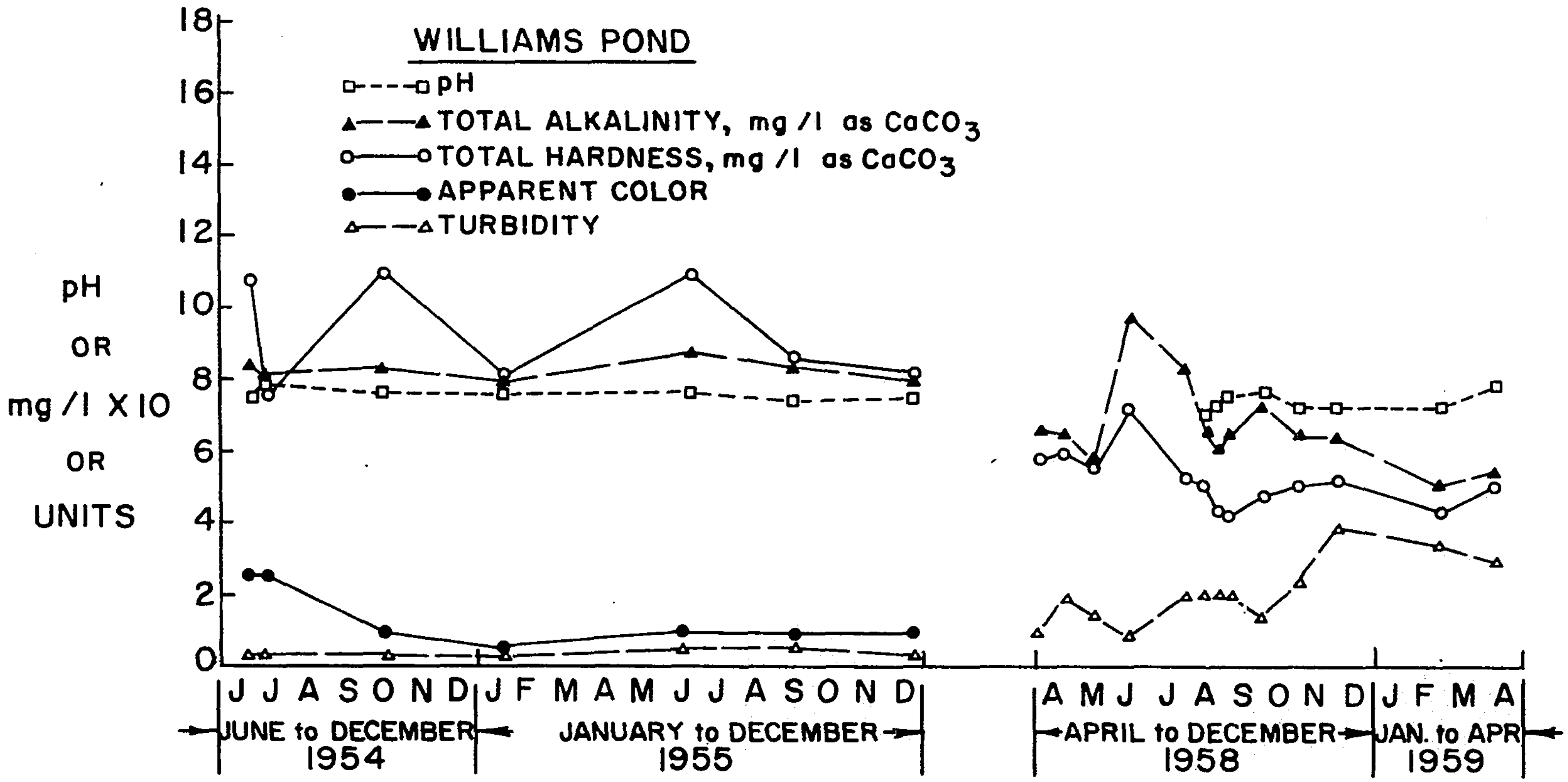
Although supporting measurements were not made, it is hypothesized that the high apparent color in newly-constructed ponds was due to the leaching of color from newly-exposed soil and organic matter; that turbidity was high due to bare soil or poor cover on the pond banks and disturbed area around the pond; and that color and turbidity were high due to a shallow depth of water which was more easily stirred by wind action and by surface water entering the pond.

Conclusions: Pond age significantly affects the color, turbidity and nitrate concentrations in pond water. These properties have greater values in newly-constructed ponds than in ponds which are two or more years old unless other influential factors are more dominant than pond age.

Effect of watershed cover and use on nitrate concentration

Watershed cover and use had little effect on the nitrate concentration in pond water. Heavily grazed watersheds, as contrasted to watersheds which were predominantly cultivated or in meadow, did not cause a higher nitrate level in the pond water. Nitrate levels were always less than 10 mg/l, the minimum concentration generally considered to constitute a

Figure 14. Variations in pH, total alkalinity, total hardness, apparent color and turbidity in the Williams pond.



WILLIAMS POND
pH
TOTAL ALKALINITY, mg / l as $CaCO_3$
TOTAL HARDNESS, mg / l as $CaCO_3$
APPARENT COLOR
TURBIDITY
pH OR mg / l X 10 OR UNITS
18
16
14
12
10
8
6
4
2
0
J J A S O N D J F M A M J J A S O N D
A M J J A S O N D J F M A
JUNE to DECEMBER 1954
JANUARY to DECEMBER 1955
APRIL to DECEMBER 1958
JAN. to APR 1959

health hazard if the water is used for infant feeding.

Even though the Williams watershed was heavily grazed by sheep and cattle in 1958-59, the maximum tested nitrate concentration in the pond water was 0.1 mg/l. The highest nitrate concentration tested for the Carpenter pond water during the same period when the Carpenter watershed was not grazed was 0.4 mg/l. The difference is not considered significant, but it is considered significant that the heavy grazing of the Williams watershed did not cause a higher nitrate level in the pond water. All older ponds, regardless of watershed cover and use, always contained less than 2 mg/l of nitrate nitrogen.

Similar results have been reported by other investigators. Very low nitrate levels were observed in 20 ponds in Missouri. Esmay, *et al.* (25) reported no measurable quantities until late fall after the ponds had begun to freeze. The highest average nitrate concentration of about 2 mg/l was found in December. Several watersheds were grazed. Hill (42) reported a range of 0 to 5.9 mg/l of nitrates and an average of less than 0.5 mg/l of nitrates in the 14 ponds which he sampled in Ohio. Amerman (2) reported a nitrate range of 0 to 1.4 mg/l for two ponds which he used as water sources for his investigations in Indiana.

Hale (34) reported a maximum nitrate concentration of 5.5 mg/l in the pond which he used for his investigation in Tennessee. He also reported that silage juices draining into the pond caused the water to have an undesirable taste. Quite possibly the above normal nitrate content was partially due to the silage juices which are extremely high in nitrites.[1]

Reporting on nitrate intoxication in livestock, Case (14) states that "nitrite was more dangerous than nitrate; it proved to be 10 to 15 times as toxic. Many farm ponds contained over 5 ppm of nitrite during 1954 and 1955, often causing intoxication in the animals that had to drink it."

Runoff water high in nitrates and nitrites could conceivably increase the total nitrogen concentration in ponds which contain a small volume of water. However, older ponds in Iowa have consistently tested low in nitrates, even when the ponds were less than one-fourth full. Apparently, the established biological life in older ponds quickly consumed the nitrogen after it entered the pond.

Conclusions: Evidence generally indicates that nitrate concentration in pond water, particularly in older ponds, is not a health hazard. Grazing of a grassed watershed does not materially affect the nitrate concentration in the pond water since established biological life in older ponds apparently consumes the nitrogen soon after it enters the pond.

<u>Effect of runoff, watershed management, and soil properties on pH, alkalinity, hardness and turbidity</u>

Interactions of numerous factors affect the pH, alkalinity, hardness and turbidity concentrations in pond water. Dilution of pond water by

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[1] Case, A. A., School of Veterinary Medicine, University of Missouri, Columbia, Missouri. Information on nitrate intoxication in livestock. Private communication. 1960.

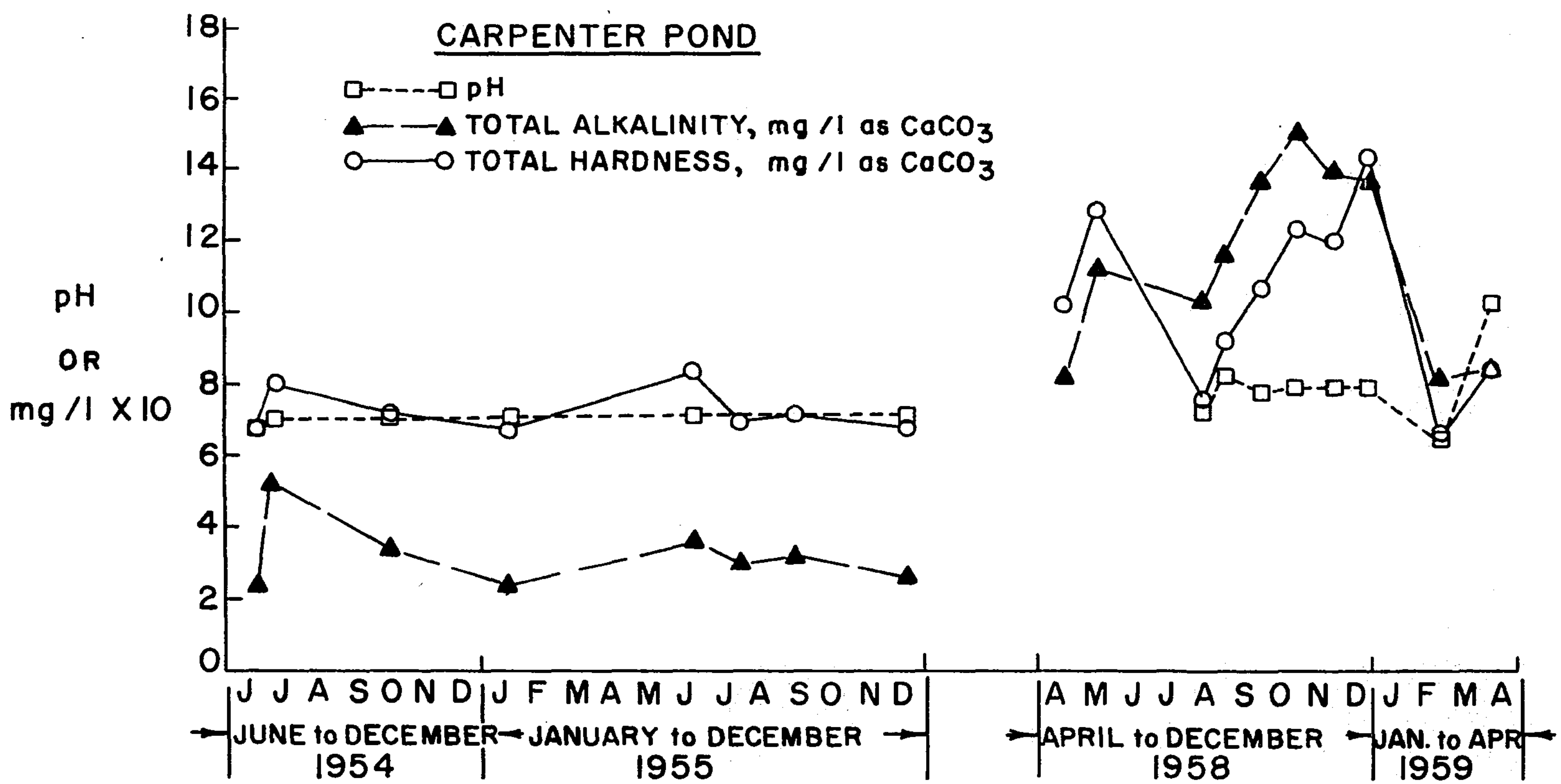
large quantities of runoff was a predominant factor in lowering the values of these properties. Hardness levels fluctuated more and were significantly higher in ponds with partially cultivated watersheds than in those with completely grassed watersheds. Discounting the short-term influence of other factors, a relationship between high hardness and low turbidity was apparent.

The newly-constructed Carpenter pond partially filled with runoff water during 1954 and 1955. As shown in Figure 15, the pH, alkalinity and hardness of the pond water was lower in 1954-55 than in 1958-59. New ponds generally contained water of low hardness, but hardness increased with time. The increased hardness was probably caused by evaporation.

The older Williams pond did not exhibit the extreme change in hardness as did the Carpenter pond from the 1954-55 testing period to the 1958-59 testing period. A change did occur in the Williams pond, however, as shown in Figure 14. Hardness levels were higher and fluctuated more in 1954-55 when the watershed was partially cultivated than in 1958-59 when the watershed was completely grassed. The opposite change occurred in turbidity levels. Turbidity levels increased when hardness levels decreased.

If we assume that the Carpenter pond reacted as an older pond in 1958-59, a comparison of results unaffected by pond age can be made for the Carpenter and Williams ponds for the 1958-59 testing period. In general, all physical and chemical properties were of greater value and fluctuated more in the Carpenter pond than in the Williams pond. Undoubtedly, the grassed Williams watershed was a greater stabilizing

Figure 15. Variations in pH, total alkalinity and total hardness in the Carpenter pond.


CARPENTER POND
pH
TOTAL ALKALINITY, mg /l as $CaCO_3$
TOTAL HARDNESS, mg /l as $CaCO_3$
pH
OR
mg /l X 10
18
16
14
12
10
8
6
4
2
0
J J A S O N D J F M A M J J A S O N D
A M J J A S O N D J F M A
JUNE to DECEMBER 1954
JANUARY to DECEMBER 1955
APRIL to DECEMBER 1958
JAN. to APR 1959

influence on water properties than the partially cultivated Carpenter watershed.

Examination of the 1958-59 data for the Wallace and Wolfe ponds in conjunction with the data for the Carpenter and Williams ponds permits further evaluation of the factors which influence hardness and turbidity.

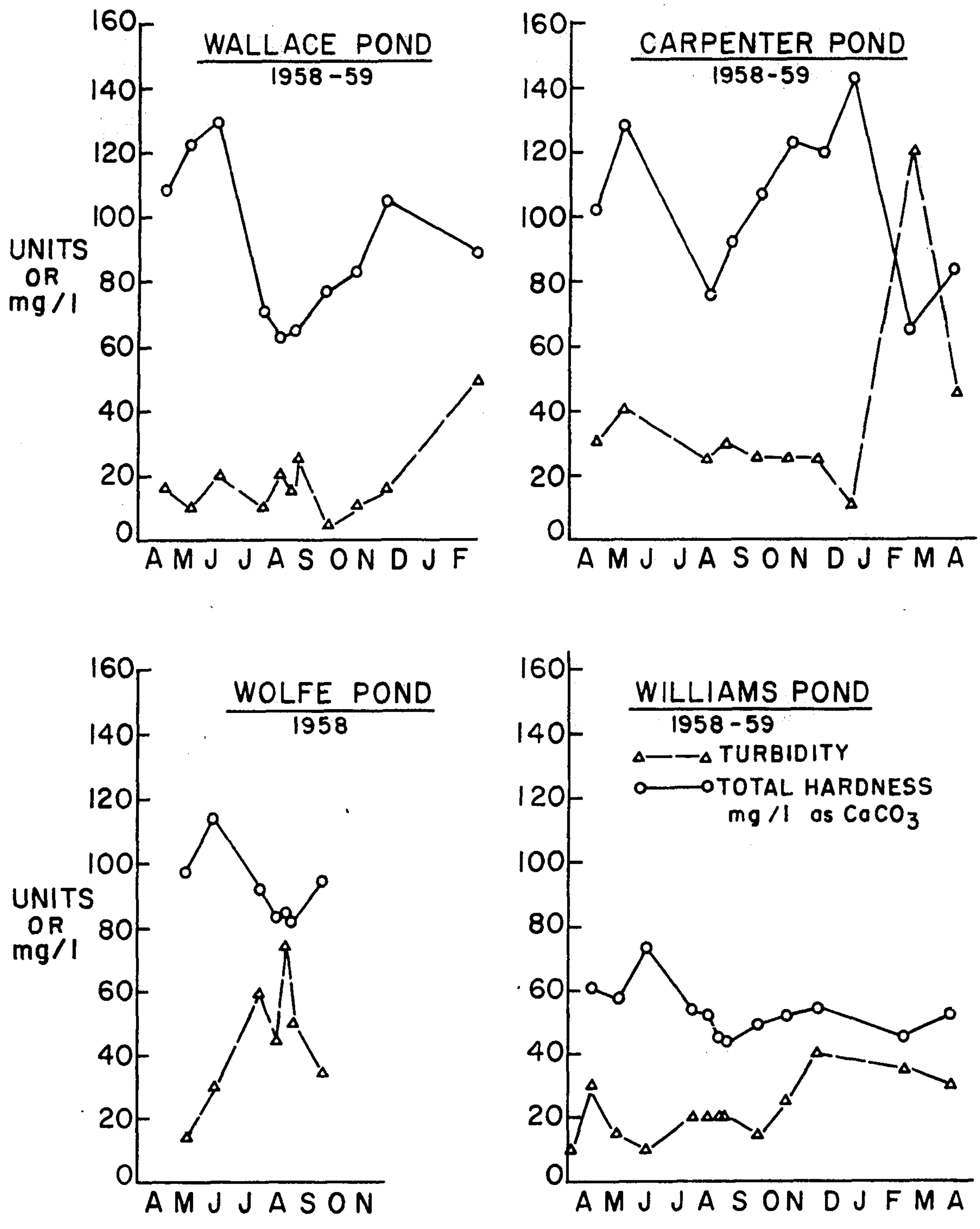
As oriented in Figure 16, data for the Wallace and Carpenter ponds, which had partially-cultivated watersheds, are plotted across the top. Data for the Wolfe and Williams ponds, which had completely grassed watersheds, are plotted across the bottom.

A comparison of data for the four ponds shows a universal reduction in hardness between the June and August sampling dates. Dilution by July rainfall caused the hardness reduction. Approximately 10 inches of rain fell in July, Table 4. This exceeded the cumulative precipitation for the preceding 6 months.

In general, the ponds were less than one-fourth full in June. Consequently, the large volumes of runoff in July materially diluted the water already in the ponds. This dilution caused major reductions in hardness, alkalinity and pH as recorded at all four ponds.

Since precipitation in excess of a trace was recorded on 13 days during July with a maximum 24-hour precipitation of 2-1/2 inches, turbidity levels in the Wallace, Carpenter and Williams ponds were not materially affected due to the large number of storms which contributed the total runoff and to the large volume of dilution water. The Wolfe pond was an exception. The turbidity level increased in July and generally throughout the summer months. Extensive algal growth was the major cause of increased turbidity and it dominated other influential

Figure 16. Variations in turbidity and total hardness in the Wallace, Carpenter, Wolfe and Williams ponds.



WALLACE POND
1958-59
CARPENTER POND
1958-59
WOLFE POND
1958
WILLIAMS POND
1958-59
TURBIDITY
TOTAL HARDNESS mg/l as $CaCO_3$
UNITS OR mg/l
160
140
120
100
80
60
40
20
0
A M J J A S O N D J F
A M J J A S O N D J F M A
A M J J A S O N

Table 4. Precipitation observed at recorder stations

Date	Indianola: Total for month, inches	Indianola: Total precipitation exceeding 1 inch in 48 hours, inches	Indianola: Dates of 48 hour period	Des Moines municipal airport: Total for month, inches	Des Moines municipal airport: Total precipitation exceeding 1 inch in 48 hours, inches	Des Moines municipal airport: Dates of 48 hour period
1958						
Jan.	0.73	none	--	0.71	none	--
Feb.	0.77	none	--	0.61	none	--
Mar.	0.60	none	--	0.61	none	--
Apr.	1.63	none	--	1.31	none	--
May	3.15	none	--	3.59	none	--
June	2.73	1.3	19 & 20	3.34	1.5	12 & 13
July	9.66	3.4	1 & 2	10.51	5.2	1 & 2
		2.5	19		2.1	19
		1.3	29 & 30			
Aug.	0.66	none	--	1.78	1.5	20
Sept.	2.89	1.1	5 & 6	4.06	1.8	5 & 6
Oct.	0.05	none	--	0.07	none	--
Nov.	2.61	2.4	17	2.00	1.9	17
Dec.	0.13	none	--	0.25	none	--
1959						
Jan.	0.52	none	--	0.79	none	--
Feb.	0.66	none	--	1.07	none	--
Mar.	2.53	1.4	25 & 26	3.94	1.7	25 & 26
Apr.	3.74	1.7	19 & 20	3.51	1.6	19 & 20

factors.

Total rainfall observed at Indianola for the next 4 months after July was slightly over 6 inches, with a maximum of 0.6 inches recorded in any 24 hour period. Little or no runoff resulted and hardness levels increased. Greater fluctuations in hardness levels occurred in the ponds with partially-cultivated watersheds than in the ponds with grassed watersheds.

The influence of watershed management, soil properties and runoff on pond water properties and the relationship between turbidity and hardness have been reported by investigators in other states.

Esmay, et al. (25) stated that "the most turbid water in this test was produced by ponds having small, well-grassed watersheds used only for the collection of water. The cultivated watershed produced pond water having about average turbidity throughout the tests and the small, well-grassed watersheds used for grazing produced water with the lowest turbidity." They also reported that pond water levels and turbidities were generally quite low when conductivities and hardnesses were relatively high, and that, in general, the harder water (more than 50 mg/l) tended to be less turbid than waters having hardnesses of less than 50 mg/l.

Daniel (23) reported that "some of the ponds that cleared up after a rain had considerable cultivated land in their watersheds while some of the ponds that stayed muddy received all or most of their water from a grassed area." Following a study of 33 Oklahoma ponds over a period of 3 years, he reported that fluctuations in turbidity were apparently due to varying soil conditions on the watershed area and/or within the pond area.

After investigating 20 ponds in Missouri, Tempel (78) hypothesized that a definite relationship existed between pond turbidity and water conductivity. A significant relationship between high water hardness and conductivity levels and low turbidity levels was also reported by Hodges and Shanklin (43). They likewise observed less fluctuation of turbidity in pond water collected from grassed watersheds than from cultivated watersheds.

By combining the data on turbidity and hardness concentrations as reported from the states of Oklahoma, Missouri and Ohio with the information obtained in Iowa, it is possible to hypothesize concerning the factors which influence the relationship between these two properties.

A comparison of the data indicates that a significant relationship exists between water hardness and turbidity levels for a relatively large number of ponds over an extended period of time. Turbidity decreases as hardness increases.

Soil properties and watershed management are undoubtedly the dominant factors which cause these variations. The older Oklahoma soils, developed on residual parent material, are more leached and lower in readily soluble minerals. Less intensively cultivated watersheds is another significant factor.

Progressing northward from Oklahoma through Missouri to Iowa, the soils are younger, inherently more productive, and higher in readily soluble minerals. Also, the younger soils developed on glacier-deposited parent materials in Missouri, Iowa and Ohio are more intensively cultivated and fertilized.

Table 5. Variations in turbidity and total hardness concentrations in pond water by states

State	Turbidity units	Total hardness, mg/l as $CaCO_3$
Oklahoma[a]	248	14
Missouri[b]	15 to 140	54 to 87
Iowa[c]	5 to 50	50 to 130
Ohio[d]	21	95

[a]Daniel (23) - average values for 30 ponds; June and July 1959.

[b]Hodges and Shanklin (43) - range in values for 47 ponds, August 1956 to May 1958.

[c]Usual range in values for 12 ponds over 3 years old, deleting extreme values caused by spring overturns and other unusual conditions; June 1954 to April 1959.

[d]Hill (42) - average values for 14 ponds; April 1958 to September 1959.

Some difference between the data reported for Missouri and for Iowa is apparent. Turbidity levels were generally lower and hardness levels were higher in Iowa than in Missouri. From the available information, it appears that pond water properties in Iowa are more similar to those in Ohio than to those in Missouri.

Conclusions: Dilution of pond water by runoff decreases the mineral content in the water. Newly-constructed ponds generally contain water of lower mineral content than older ponds since the new ponds are filled by recent runoff. Mineral content increases with time in all ponds due to evaporation until runoff water of low mineral content dilutes the pond water.

Watershed cover and use influence pond water properties. A grassed watershed has a stabilizing influence on the physical and chemical properties of the pond water. In contrast, great variability in water properties occurs in ponds with cultivated watersheds. Ponds with cultivated watersheds generally contain water of higher mineral content than ponds with grassed watersheds.

Discounting the short-term influence of other factors, a relationship exists between hardness and turbidity levels. A high hardness content, and generally associated high specific conductance, is related to a low turbidity level. Pond water high in turbidity will generally be low in hardness, assuming that the suspended solids are predominantly colloidal material and do not include extensive algal and other vegetative material.

Soil properties influence pond water properties. Runoff water from a youthful, fertile soil is higher in hardness and total mineral content than runoff from an older soil which is more leached and lower in readily soluble minerals.

Effect of ice cover, snow melt, overturning and liming of the watershed on physical and chemical properties

The singular influence of various factors on pond water properties was frequently difficult to positively identify. An evaluation of the data did permit at least a partial separation of the changes in water properties due to ice cover, snow melt, overturning and liming of the watershed.

The effect of an ice cover over the pond, as it contributes to a stable condition and low water color and turbidity, was particularly apparent for the Carpenter pond. The lowest color and turbidity levels were obtained in December and January, as shown in Figure 13.

In contrast, the spring and fall overturns caused great disturbances and fluctuations in water properties. The changes in properties due to the 1958 spring and fall overturns are indicated by the plotted data in Figures 13, 14 and 15 for the Carpenter and Williams ponds.

The spring overturn of 1959 was particularly disturbing to the Carpenter pond since it was accompanied by snow melt and runoff. The large volume of cold water entering the pond evidently caused a more abrupt reversal within the pond.

A history of four successive samplings of the Carpenter pond is given in Table 6.

A relatively stable condition existed through December and January as a result of the ice cover. However, approximately 1/3 inch of rainfall and considerable snow melting occurred several days previous to the sampling on February 25. The pond level had risen and the water was highly colored and frothy. Pond water temperatures were 34° F. at the surface and 38° F. at the bottom. Observations indicated that the spring overturn was in process. A surface water temperature of 42° F. on March 20 indicated that the reversal had been completed. The subsequent sampling on April 10 showed that major fluctuations in properties had occurred. The pond level had risen about 6 inches since the last sampling date and the watershed had been heavily limed. The water was highly colored and appeared black in reflected light.

Table 6. Variations in water properties due to climatic conditions and watershed treatment, Carpenter pond

Sampling date	Turbidity units	Total hardness, mg/l as $CaCO_3$	Total alkalinity, mg/l as $CaCO_3$	pH	Nitrate, mg/l as nitrate nitrogen
11-28-58[a]	25	120	139	7.9	0.1
12-29-58[b]	10	143	137	7.9	0.1
2-25-59[c]	120	66	82	6.5	0.4
4-10-59[d]	45	87	87	10.2	0.3

[a]Pond ice cover about 2 inches thick.

[b]Pond ice cover about 6 inches thick.

[c]Pond surface, 34° F.; pond bottom, 38° F.

[d]Pond surface, 48° F.

Although it is difficult to separate the interactions of the spring overturn and the effect of dilution by snow melt and rainfall, it is supposed that the overturn was primarily responsible for the increased turbidity and color; that runoff water increased the nitrate level; that dilution by the runoff water caused the reduction in hardness, alkalinity and pH; and that the lime application on the watershed contributed to the increase in hardness and pH and the reduction in turbidity as tested on April 10.

Hill and Schwab (40) reported the average color, turbidity and odor levels for 14 Ohio ponds to be highest in March and April. The

Ohio data indicates that the spring overturn has a more pronounced effect on color and turbidity than the fall overturn. Eight of the ponds had the highest color level and five had the highest turbidity level immediately following the spring overturn.

Conclusions: An ice cover has a stabilizing influence on pond water properties and low turbidity and color levels will result. In contrast, the fall and spring overturns disturb the pond and the highest turbidity and color levels will generally occur following an overturn. Spring overturns usually cause more abrupt and greater changes in water properties than fall overturns. Dilution water, as the result of either snow melt or rainfall, will lower the hardness, alkalinity and pH levels. Lime applications or the addition of other soil amendments to the watershed can materially affect pond water properties. In general, pond water will be highest in color, turbidity and odor in the spring months in the northern latitudes.

Effect of pond size, watershed size and the watershed-to-pond-size ratio on color and turbidity

No effect of pond size or watershed size alone on color and turbidity was apparent in this investigation. However, the watershed-to-pond-size ratio, as it affected the volume of runoff and the maintenance of a constant water level, was considered to be an influential factor.

If the effects of overturn and pond age are excluded, the most apparent cause for change in color was the submergence of weeds with a rising pond level. Weeds, which became established on the bare pond banks as the pond levels receded, contributed color to the water as the result of their decomposition after submergence.

Esmay, et al. (25) reported that surface area and volume of ponds did not significantly affect the water turbidity. However, Hodges and Shanklin (43) reported that, in general, the larger ponds tended to have less turbid waters than smaller ponds. Hill (42) observed no significant relationship between turbidity and watershed area.

Conclusions: The relationship of the watershed area to the pond storage capacity is more significant as it affects the color of the pond water than the singular effect of either the watershed area or pond storage capacity.

An adequate watershed-to-pond-size ratio is desirable to maintain a fairly constant pond water level near overflow capacity. A fluctuating water surface may increase the color concentration due to the submergence and decay of vegetation with a rising water level.

Iron and manganese concentrations in pond water

A combined iron and manganese concentration exceeding 0.3 mg/l may cause staining of laundry and unpalatable tastes in some foods and beverages. Iron concentrations never exceeded 0.3 mg/l in the ponds included in this study and were generally less than 0.1 mg/l. No complaints with respect to problems caused by excessive iron or manganese were received from families using pond water.

Hill (42) reported a range of 0.05 to 1.55 mg/l and an average of 0.38 mg/l of iron in 14 Ohio ponds. Higher iron and manganese concentrations were observed by Amerman (2) throughout the fall and winter seasons. He reported ranges of 0.1 to 1.0 mg/l for iron and 0.1 to 1.4

mg/l for manganese in two Indiana ponds. A Tennessee pond water supply tested 2.6 mg/l of iron and 1.2 mg/l of manganese (34).

Conclusions: Tests and inquiries directed to pond water consumers indicated that iron and manganese concentrations were not excessive in Iowa pond water supplies. However, combined iron and manganese concentrations in pond water exceeding 0.3 mg/l have been reported by investigators in other states. Treatment for iron and manganese removal may be desirable for some pond waters.

Factors affecting bacteria counts

Various factors influenced bacteria counts, but a disturbance of the pond by an overturn or by runoff water entering the pond generally caused the highest counts to occur in samples which were taken near the pond surface. The high standard plate counts observed in July and August reflect the effect of runoff water entering the ponds. The combined effect of runoff and the spring overturn caused the high counts which were observed in February and March of 1959, Table 7.

Coliform organisms occurred more frequently following rainfall and runoff from the heavily grazed watershed Williams than from the partially cultivated watersheds Carpenter and Wallace. Coliform organisms were observed in the ponds more frequently during the cooler fall and winter months than during the hotter summer months.

Hill (42) reported that maximum bacteria counts were observed during July, August and September in Ohio. Esmay, et al. (25) reported that bacteria population peaks occurred in October and November in Missouri. Quite possibly the discrepancy can be explained on the basis of latitude and a corresponding variation in solar radiation as it affects water

Table 7. Standard plate and coliform counts in pond water samples

Sampling date	Pond installations							
	Carpenter		Williams		Wallace		Wolfe	
	Standard plate count, no./ml	Coliform count, no./100 ml	Standard plate count, no./ml	Coliform count, no./100 ml	Standard plate count, no./ml	Coliform count, no./100 ml	Standard plate count, no./ml	Coliform count, no./100 ml
1958								
3-21	1000	0	100	0	---	---	---	---
4-19	600	0	120	0	710	0	---	---
5-17	1000	0	100	2	500	0	230	0
6-13	---	---	370	0	660	98	1100	0
7-28	---	---	800	0	2700	0	300	0
8-13	1000	0	680	0	270	0	240	0
8-23	---	---	4600	0	2400	0	430	---
9-2	630	0	340	0	250	0	320	---
10-3	300	2	460	3	90	3	---	---
10-17	---	---	200	40	20	0	---	---
10-24	550	10	---	---	---	---	---	---
10-31	250	0	200	55	80	0	---	---
11-28	150	0	500	33	140	0	---	---
12-29	480	0	---	---	---	---	---	---
1959								
2-25	TNC[a]	330	TNC[a]	0	4000	34	---	---
3-20	5600	0	360	16	3300	30	---	---

[a]TNC, too numerous to count, 3000+ organisms.

temperatures and ultraviolet light intensities.

Conclusions: A pond disturbance by an overturn or by runoff entering the pond increases the bacteria count in the water near the pond surface. Seasonal variation in solar radiation also influences bacteria counts. Coliform organisms persist longer in the cooler months than in the warmer months. Coliform organisms occur more frequently in ponds with grazed watersheds than in ponds with cultivated or ungrazed watersheds.

Factors Influencing Water Properties During and After Removal

Effect of the type of inlet on water properties

The type of inlet used for withdrawing water from a pond and its location within the pond affected water properties. An inlet which withdrew water from the upper portion of the pond was superior to an inlet which was located on or near the bottom of the pond because water of less desirable quality was obtained from the lower portion of the pond.

Various types of inlets were observed. Two types of inlets which were located on or near the pond bottom are shown in Figure 17. The barrel inlet usually consisted of a vertical perforated pipe which was surrounded by a barrel filled with gravel and rock. Water withdrawn through barrel inlets generally contained more color and suspended solids than the water which was closer to the surface of the pond, Table 8.

The beehive inlet, and modifications of similar construction and location, generally proved unsatisfactory. Frequent complaints were received concerning the undesirable odor in water withdrawn from the lower portion of the pond through these inlets. Also, they were difficult to clean after they became clogged with sediment.

Figure 17. Inlets located on or near the bottom of the pond.

A barrel inlet which is located about 3 feet above the deepest portion of the pond. Water which is withdrawn through the barrel inlet flows by gravity through a pipe in the earth fill.

A brick beehive inlet which is constructed on the bottom of the pond. Water is withdrawn through a pipe which is enclosed within the brick beehive.

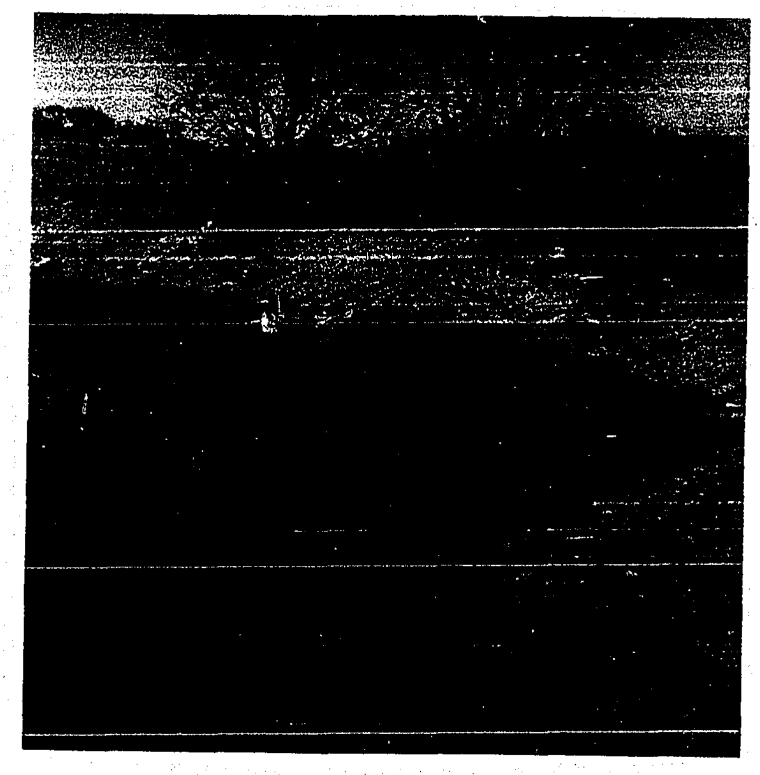


Table 8. Variations in apparent color and turbidity with depth of water removal for the pond

Pond	Sampling date	Sampling location	Apparent color units	Turbidity units
Wallace[a]	6-25-54	pond[b]	35	8
		hose bib[c]	250	105
	7-12-54	pond	20	2
		hose bib[c]	35	15
Carpenter	1-19-55	pond	125	8
		filter inlet[d]	300	55
	6-20-55	pond	300	90
		filter inlet[d]	500	140

[a]Wallace pond No. 1 had a barrel inlet; pond No. 2 had a trench filter.

[b]Pond samples were taken 6 inches below the water surface.

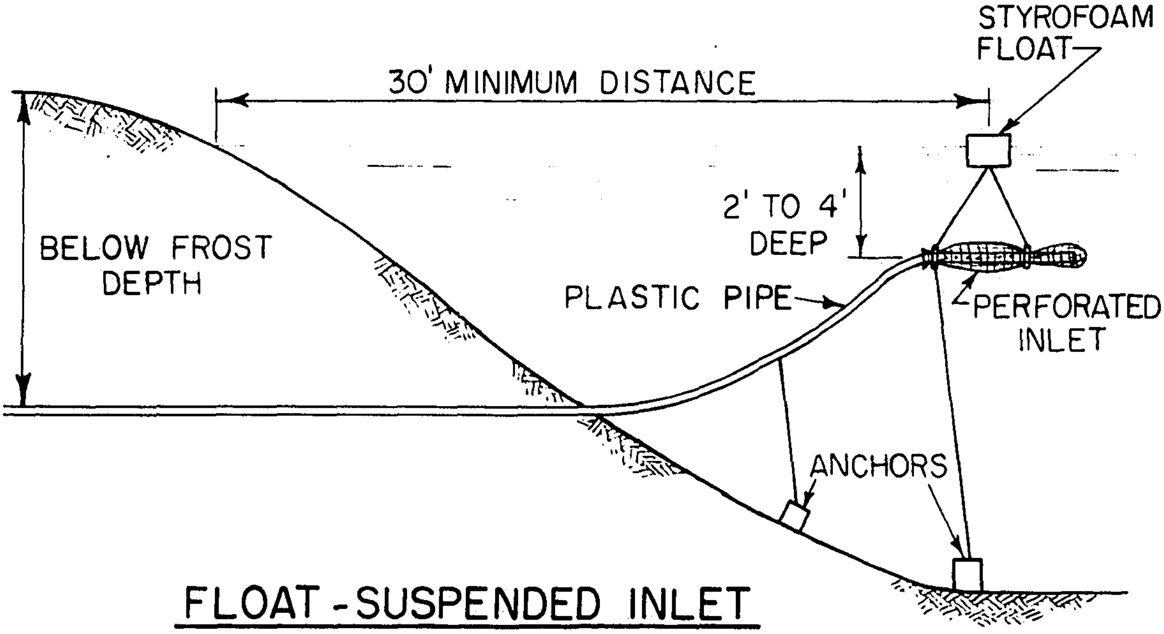
[c]Effluent from barrel inlet without treatment except chlorination.

[d]Effluent from barrel inlet.

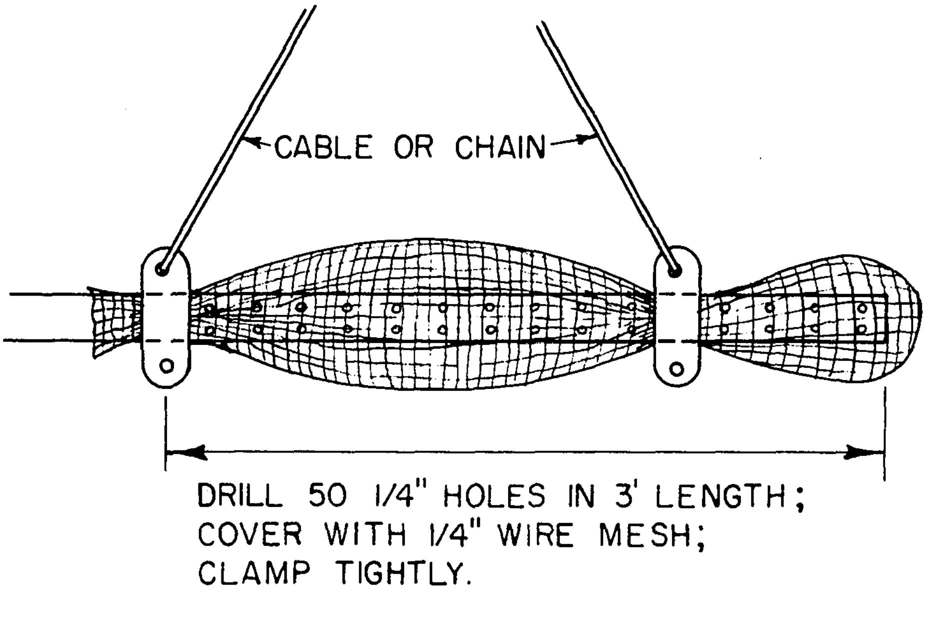
Whereas the porous brick and concrete block beehive inlets and commercially available modifications of the beehive inlet were generally located at the bottom of the pond, the float-suspended inlet was located near the pond surface. The construction features and installation of a float-suspended inlet are shown in Figures 18 and 19.

The recommended positioning of the inlet with respect to the water surface has been controversial. Various depths of submergence from a few inches to 60 inches have been recommended (42, 44, 53, 62).

Figure 18. Construction and installation plans for a float-suspended inlet.



FLOAT - SUSPENDED INLET

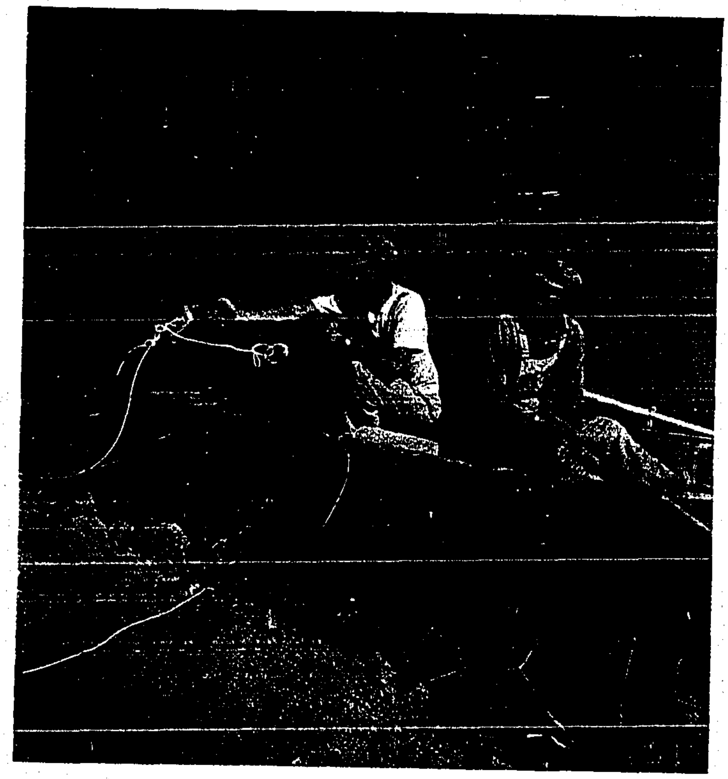


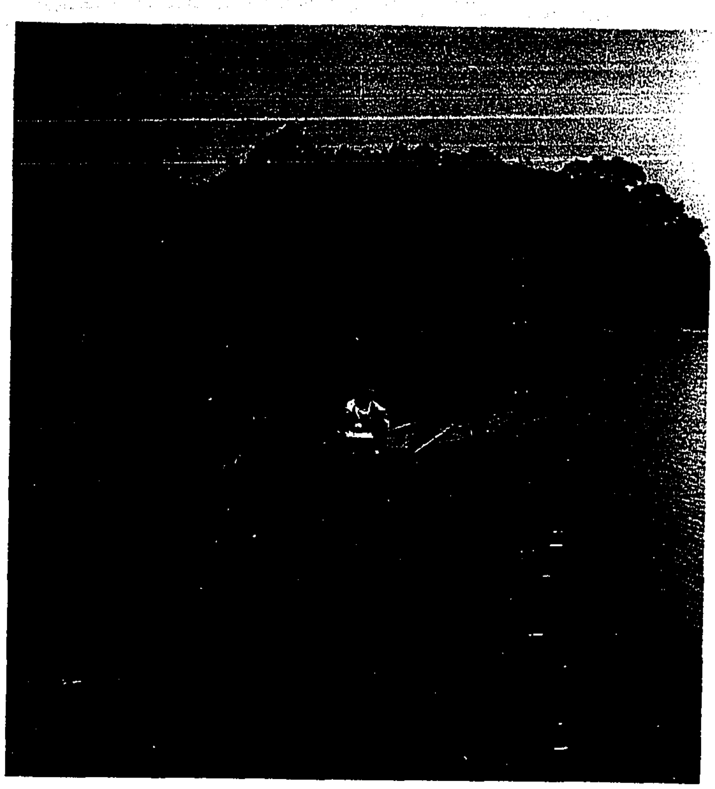
PERFORATED PLASTIC PIPE INLET

Figure 19. A float-suspended inlet installation.

The perforated end of the plastic pipe, wrapped with a wire mesh, was attached to a barrel float and to a concrete block anchor with wire-core plastic clothesline.

An additional concrete block anchor was necessary to lower the buoyant plastic pipe below anticipated ice depth.





Hill (42) reported that no appreciable differences in color and turbidity levels existed in the depth range of 12 to 60 inches for ponds over 6 feet deep. In general, color and turbidity levels were only 1 to 3 units higher at 24 inches than at 12 inches. Harlock and Dowlin (37) reported that the top 3 feet of water had the greatest concentration of algae and greatest chlorine demand. Algae are found in greater abundance near the surface and some species frequently form a floating scum (3).

Conclusions: A float-suspended inlet, located in the upper portion of the pond, permits the withdrawal of higher quality water than any other type of inlet which might be placed on or near the bottom of the pond. The desirable depth of submergence can range between 24 and 48 inches in farm ponds which are at least 8 feet deep. This depth range will avoid concentrated algal growth near the surface and higher color, turbidity and odor levels near the bottom. A minimum depth of 24 inches is necessary in Iowa to place the inlet below the depth of ice formation.

Effect of integral filters on water properties

Integral filters, in general, did not consistently produce an effluent of desirable quality. The effluent was occasionally of less desirable quality than untreated water in the upper portion of the pond. If an integral filter became clogged with sediment, it was difficult to clean. Filter media replacement was sometimes necessary to restore the required flow rate.

Various types of integral filters, constructed either within, under or at the side of the pond, were observed during the exploratory period in 1954-55. The type of integral filter most commonly used in Iowa is the sand-filled or gravel-filled trench connecting the pond and a well beside the pond. A trench filter was constructed on the Tyler farm, an I.S.U. Foundation Farm, in 1952. The effect of this sand-filled trench filter on turbidity is shown in Table 9.

Table 9. Effect of a trench filter on turbidity reduction

Sampling date	Sampling location	Turbidity units
5-11-54	pond	750
	clear well	8
6-25-54	pond	32
	clear well	1

Pond water turbidity was extremely high on 5-11-54 due to recent runoff and to pigs wallowing in the shallow water. The low effluent turbidities on both sampling dates indicated that the sand-filled trench was capable of reducing turbidity to an acceptable level under extremely adverse conditions. However, a problem was encountered with this trench filter because of its effectiveness in the removal of turbidity. Clogging of the filter entrance resulted and an adequate flow rate to satisfy water demands could not be restored.

A sand-filled trench filter in the Wallace installation also clogged soon after its installation, and the sand was replaced with pea gravel.

The pea gravel has functioned satisfactorily for 4 years without clogging. As shown in Figure 20, the pea gravel trench filter was effective in reducing suspended solids. Whereas the pond water averaged 21 units of turbidity, the filter effluent averaged 5 units of turbidity during the 12 month testing period. The filter effluent was also lower and fluctuated less in pH than the water in the upper portion of the pond. However, the Wallace filter installation had an extremely adverse effect on water hardness. The trench filter effluent ranged from 240 to 340 mg/l of hardness as compared to a range of 60 to 130 mg/l of hardness for the samples taken just below the pond surface.

The pea gravel filter bed in the Wolfe installation has not clogged in seven years of operation. In 1958-59, it maintained an effluent turbidity of less than 20 units when the influent turbidity averaged 43 units. Effluent turbidity and pH were lower and fluctuated less than the turbidity and pH in the upper portion of the pond, Figure 21. The filter bed effluent did not increase in hardness as much as the effluent from the trench filter.

Data obtained during the exploratory period on a buried collector tile installation, Table 10, indicated that greater concentrations of color, turbidity and hardness occurred in the collector tile effluent than in the water near the pond surface. However, data obtained in 1958-59, Figure 22, indicated that a greater amount of turbidity occurred more frequently in the pond surface water than in the collector tile effluent.

Of the physical and chemical properties which were tested in 1958-59, the most significantly and adversely affected property was total

Figure 20. Variations in turbidity, pH and total hardness as affected by filtration, Wallace pond.

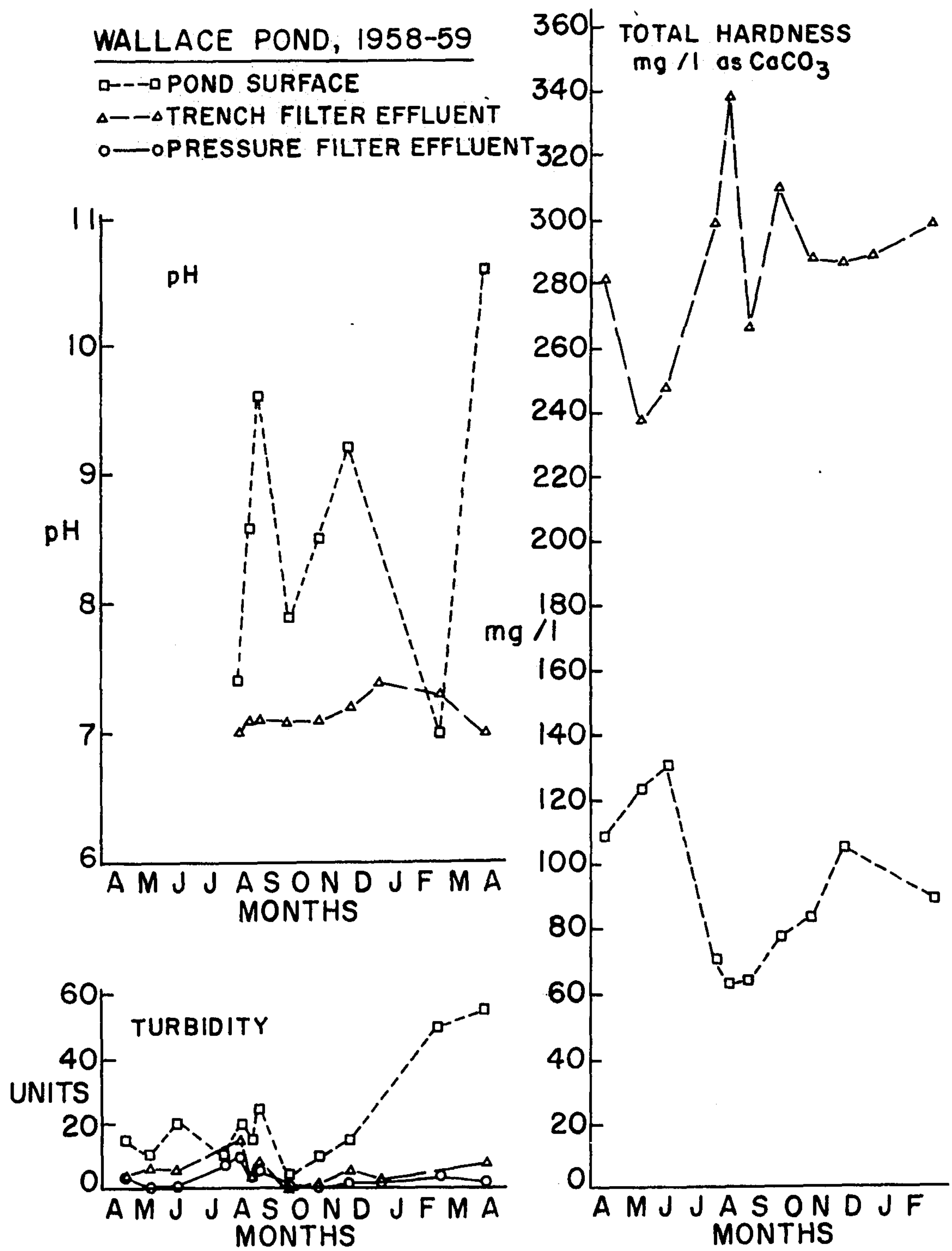

WALLACE POND, 1958-59
POND SURFACE
TRENCH FILTER EFFLUENT
PRESSURE FILTER EFFLUENT
pH
pH
A M J J A S O N D J F M A
MONTHS
TURBIDITY
UNITS
A M J J A S O N D J F M A
MONTHS
TOTAL HARDNESS
mg /l as $CaCO_3$
mg /l
A M J J A S O N D J F
MONTHS

Figure 21. Variations in turbidity, pH and total hardness as affected by filtration, Wolfe pond.

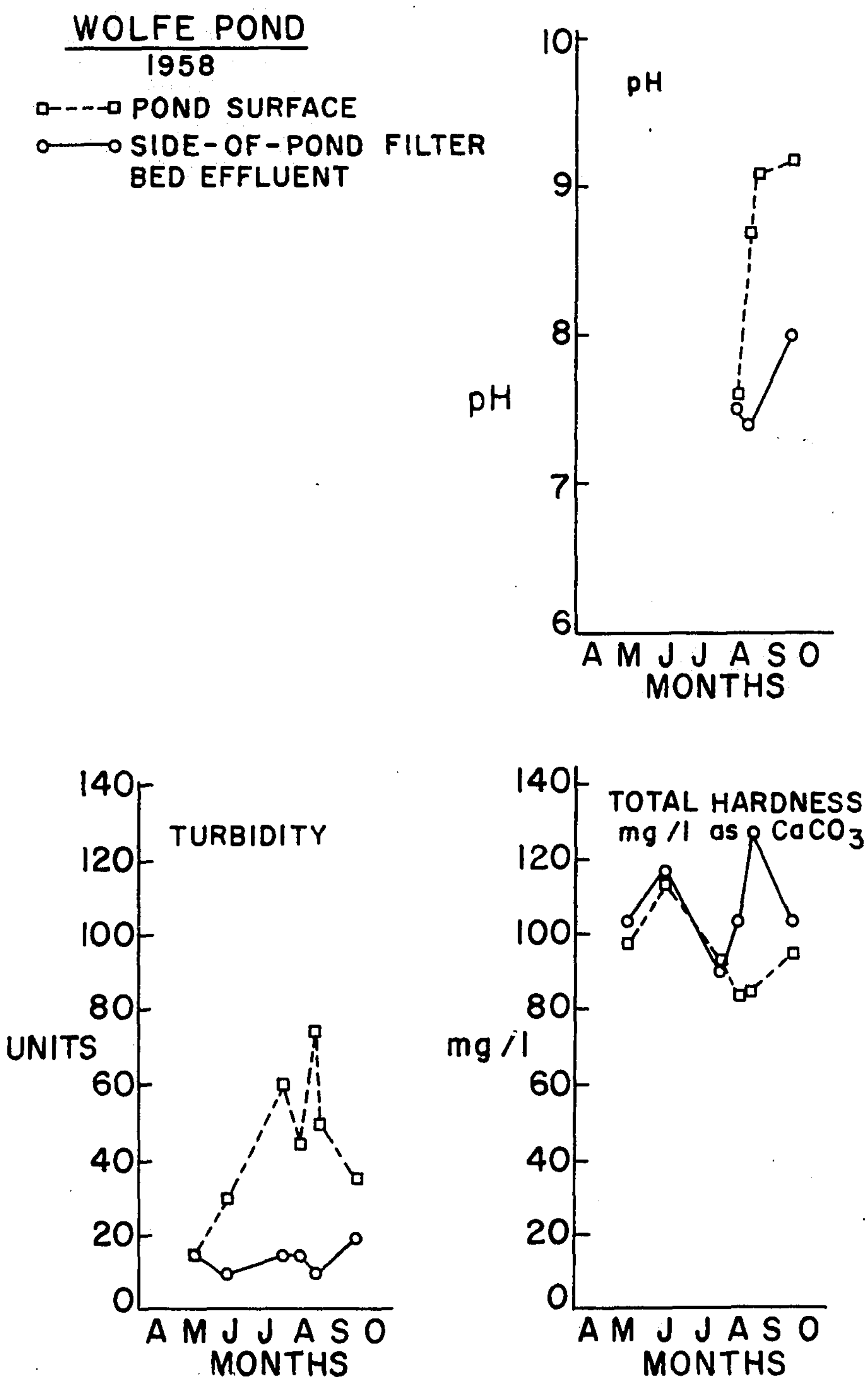
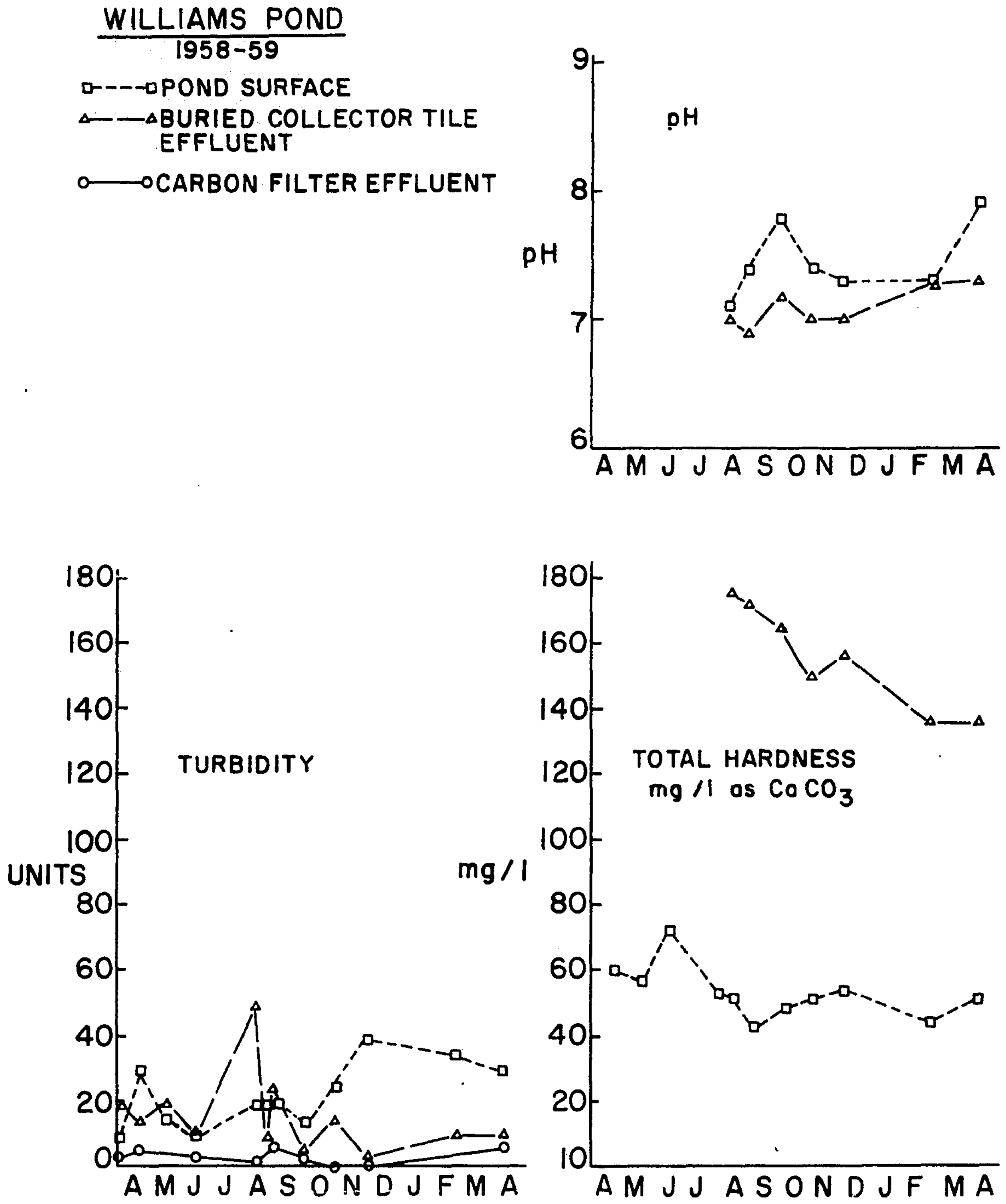

WOLFE POND
1958
POND SURFACE
SIDE-OF-POND FILTER
BED EFFLUENT
pH
pH
10
9
8
7
6
A M J J A S O
MONTHS
TURBIDITY
UNITS
140
120
100
80
60
40
20
0
A M J J A S O
MONTHS
TOTAL HARDNESS
mg /l as CaCO3
mg /l
140
120
100
80
60
40
20
0
A M J J A S O
MONTHS

Figure 22. Variations in turbidity, pH and total hardness as affected by filtration, Williams pond.



WILLIAMS POND
1958-59
POND SURFACE
BURIED COLLECTOR TILE EFFLUENT
CARBON FILTER EFFLUENT
pH
9
8
7
6
A M J J A S O N D J F M A
TURBIDITY
UNITS
180
160
140
120
100
80
60
40
20
0
TOTAL HARDNESS
mg /l as $CaCO_3$
mg / l
10

Table 10. Effects of a buried collector tile and a precoat carbon filter on color, turbidity, hardness and pH, Williams installation

Sampling date	Sampling location	Apparent color units	Turbidity units	Total hardness, mg/l	pH
6-25-54	pond	25	3	108	7.5
	clear well	45	10	156	7.8
	post carbon	10	2	---	7.3
7-2-54	pond	25	6	108	7.5
	clear well	125	60	168	7.7
	post carbon	10	3	---	7.3
7-12-54	pond	25	3	76	7.8
	clear well	35	6	140	7.4
	post carbon	10	1	148	7.1

hardness. The buried collector tile effluent generally contained 80 to 120 mg/l more hardness than the pond water at the surface.

Total alkalinity, iron and nitrate tests were made in 1958-59 in addition to turbidity, pH and total hardness. None of the three types of integral filters had any significant effect on iron and nitrate concentrations. The effect of the filters on total akalinity was similar to that for total hardness. Total alkalinity values were materially greater in the effluent from the buried collector tile and trench filter than in the untreated pond water at the surface.

Bacteriological examinations of effluent from all types of integral filters indicated that none would consistently produce a safe water. After testing 30 trench filters in Missouri, Shanklin (71) concluded that none of the filters would consistently produce a safe water, and that the filters were generally incapable of reducing the effluent turbidity to less than 10 units.

Hill (42) reported that a buried collector tile with 18 inches of gravel cover produced an effluent of variable quality which was consistently less desirable in turbidity, color, odor and bacteria concentrations than water which was withdrawn through a float-suspended inlet.

Conclusions: Integral filters remove suspended solids from pond water. The sand-filled trench filter is more effective in turbidity reduction than the trench filter which contains a coarser filtering media. However, the finer media is more subject to rapid clogging. An integral filter is difficult to clean unless the pond water level is lowered. Replacement of the filter media may be necessary to restore the original filtering rate.

Pea gravel filtering media, in either a trench filter or a filter bed, serves as an effective roughing filter. Generally, pea gravel filtering media will produce an effluent containing less than 20 units of turbidity, but it will not consistently produce an effluent containing less than 10 units.

Effluent from integral filters is always higher in total hardness and total alkalinity than untreated water in the upper portion of the pond. In general, the quality of effluent from a pea gravel filter bed is superior to the effluent from a buried collector tile or pea gravel trench filter. None of the integral filters will produce a safe water.

Effect of coagulation-sedimentation on water properties and filtration

Pretreatment for the removal of color and turbidity through coagulation and sedimentation has been used either prior to or subsequent to the removal of water from ponds.

A gypsum treatment of the Carpenter pond on October 1, 1954, was effective in materially reducing both color and turbidity, Figure 13. The gypsum was hand-spread from the shore at the rate of twelve pounds per 1000 cubic feet of water. Other investigators (25, 67, 78) have reported the successful use of calcium or aluminum sulfate for water clarification by pond treatment. Rather than treating the entire pond, Daniel (22) suggested the use of a small pond below the main pond as a coagulation-sedimentation basin for water clarification.

Daniel (23) has also successfully used coagulants subsequent to water removal from the pond. His studies indicate that a rapid mix of about 15 minutes followed by a slow mix of about 2 hours provided the optimum conditions for proper flocculation with alum. However, he reported that improper flocculation would reduce filter runs and increase the required frequency of filter cleaning. This same warning was given by Babbitt and Doland (3), who did not recommend coagulation-sedimentation immediately prior to slow sand filtration. Hale (34) experienced difficulty in obtaining the desired flocculation, and short runs resulted. He observed that plain sedimentation was superior to coagulation-sedimentation in color and turbidity removal and in increasing the length of run.

Conclusions: Pond treatment with calcium or aluminum sulfate will satisfactorily reduce color and turbidity in highly turbid ponds.

Coagulation-sedimentation immediately prior to slow sand filtration is difficult to control and unsatisfactory results will often occur.

Observations of the slow sand filter in the Carpenter installation

The slow sand filter in the Carpenter installation had an initial maximum filtering rate of 100 gallons per day per square foot of filter surface. However, the average filtering rate from June 1954 to July 1955 was about 50 gallons per day per square foot. The filter was cleaned by the farm tenant approximately every month during the first year of operation. Effluent of acceptable clarity was produced as indicated by observations and random tests. Even when the filter influent was as high as 140 units of turbidity, the effluent was less than 5 units. This reduction in turbidity occurred even when less than 12 inches of filter sand remained in the filter. The average run during the first year of operation, which included extremely high pond water turbidities as shown in Figure 13, yielded about 1500 gallons of filtrate per square foot of filter surface.

Following sand replacement in July 1955, the filter was operated by the same farm tenant. The average length of run between cleanings was about 6 weeks for the period from July 1955 to March 1957. The average run produced about 2500 gallons of filtrate per square foot of filter surface. Lower water turbidities and filtering rate caused the increase in volume of filtrate per run. The filter sand was replaced for a second time in March 1957, 20 months and an estimated two million gallons of water after the first replacement.

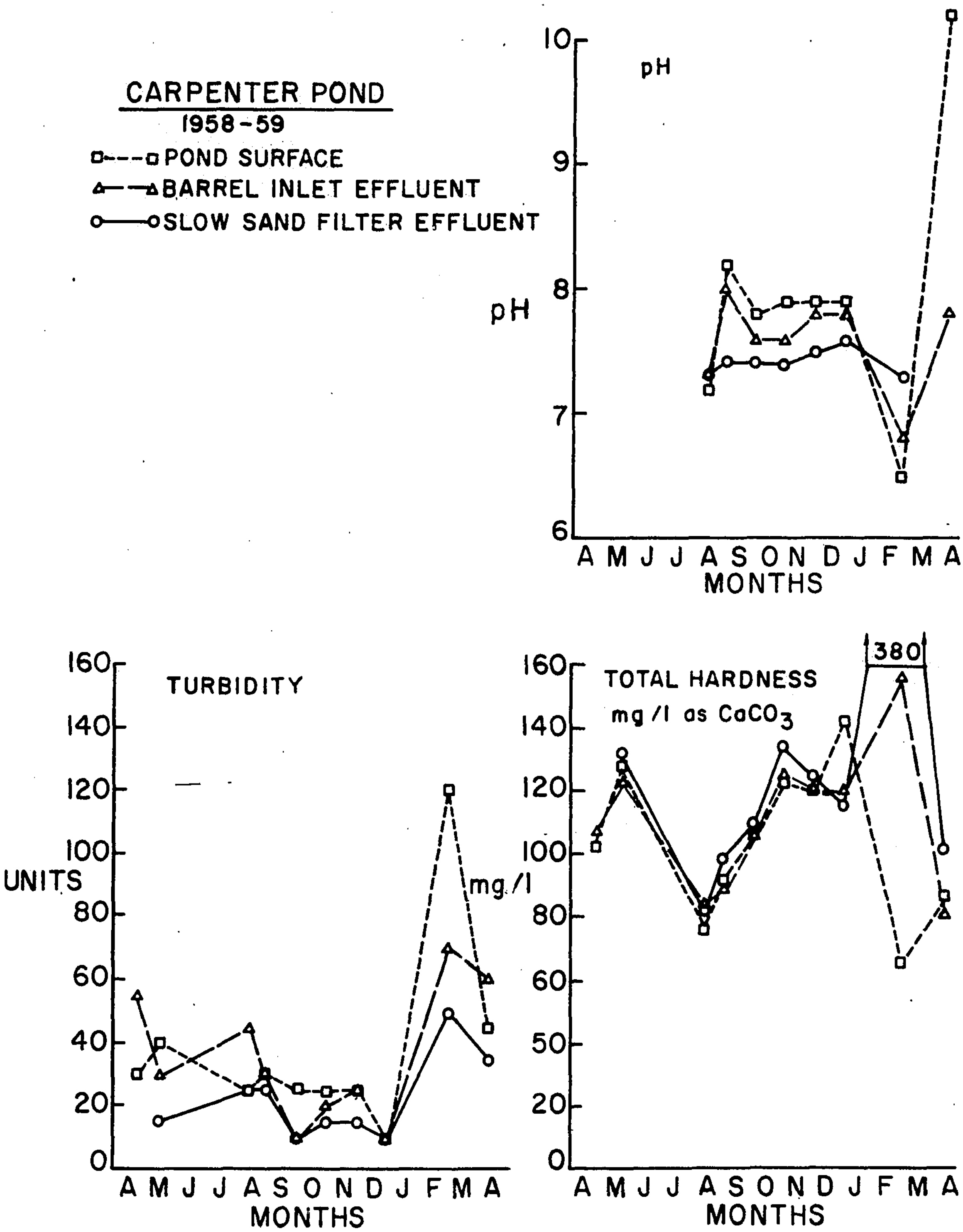
A change in farm tenancy in March 1957 resulted in a change in water demand and in filter management. Less water was used because of decreased livestock numbers. The filter was cleaned three times in the next seventeen months before the sand was again replaced. Holes were occasionally opened in the filter bed by poking in lieu of cleaning. The high effluent turbidities in August 1958 and February 1959, Figure 23, resulted from the opening of holes in the filter bed.

The filter sand was replaced a third time on August 10, 1958, and a fourth time March 1, 1959. High effluent turbidities were obtained in September 1958 and April 1959, the first sampling dates following sand replacements. The results were attributed to dirty sand and the need for additional filter aging.

Total hardness and pH. Total hardness of the filter effluent was not greatly affected by passage through the slow sand filter. The increased hardness in the effluent was generally less than 10 mg/l. An exception was observed in February 1959. The drastic changes which occurred as the result of the spring overturn produced 380 mg/l of total hardness in the filter effluent. This was three times more hardness than was tested on any other sampling date. The hardness increase was attributed to a carbonate unbalance as indicated by the low filter influent pH of 6.8. After filtration, the pH was 7.3. Except for the disturbance of pH by the overturn, the pH of the filter effluent was consistently less than the pH of the influent. Filter effluent pH ranged between 7.3 and 7.6.

Apparent color, iron and nitrate. The Carpenter pond was highly colored during the first year following construction, Figure 13. Random samplings in 1954-55 indicated that the color concentration was

Figure 23. Variations in turbidity, pH and total hardness as affected by filtration, Carpenter pond.


CARPENTER POND
1958-59
POND SURFACE
BARREL INLET EFFLUENT
SLOW SAND FILTER EFFLUENT
pH
pH
10
9
8
7
6
A M J J A S O N D J F M A
MONTHS
TURBIDITY
UNITS
160
140
120
100
80
60
40
20
0
A M J J A S O N D J F M A
MONTHS
TOTAL HARDNESS
mg /l as CaCO3
mg./l
380
160
140
120
100
80
60
50
20
0
A M J J A S O N D J F M A
MONTHS

materially reduced by slow sand filtration. An extremely high influent color of 300 units was reduced to 30 units in the effluent. Iron and nitrate concentrations were observed in both the filter influent and effluent in 1958-59. Due to the low levels of iron and nitrate in the raw water, generally less than 3 mg/l for both, no effect of the slow sand filter was discernible.

Bacteria. Investigations concerning the type and number of bacteria in the filter influent and effluent indicated a general reduction in total bacteria, coliform-like bacteria, and food-spoilage and milk-spoilage bacteria as the result of slow sand filtration, Tables 11, 12 and 13. However, all organisms were generally prevalent in the effluent. The effluent occasionally contained a greater number of bacteria than the influent.

Similar results were obtained for standard plate and coliform counts in 1958-59, Table 14.

Results obtained on 8-13-58 and 3-20-59, the first sampling dates following sand replacement, indicate the effect of dirty sand and lack of filter aging on bacteria populations. The high counts obtained on 2-25-59 were undoubtedly due to the combined effects of the spring overturn, large volumes of new water entering the pond and the opening of holes in the filter bed to increase the flow rate. Other high counts which occurred throughout the entire testing period may have been caused by filter mismanagement.

Observations of other slow sand filters

Turbidity. Neglecting the high effluent turbidities attributed to

Table 11. Total bacteria counts in the slow sand filter influent and effluent, Carpenter installation

Sampling date	Bacteria number/ml			
	Nutrient agar		Tryptone-glucose extract	
	Influent	Effluent	Influent	Effluent
8-2-55	510	260	60	41
8-17-55	3000+	3000+	3000+	3000+
8-25-55	3000+	300	3000+	3000+
9-13-55	3000+	3000+	3000+	3000+
12-19-55	95	82	645	40
1-19-56	150	190	500	80

Table 12. Coliform-like bacteria in the slow sand filter influent and effluent, Carpenter installation

Sampling date	Bacteria number/ml			
	Eosin-methylene blue agar		Desoxycholate lactose agar	
	Influent	Effluent	Influent	Effluent
8-2-55	6	13	10	0
8-17-55	15	6	51	25
8-25-55	--	3000+	1	1
9-13-55	20	180	14	1
12-19-55	7	0	1	0
1-19-56	100	20	--	--

Table 13. Food-spoilage and milk-spoilage bacteria in the slow sand filter influent and effluent, Carpenter installation

Sampling date	Bacteria number/ml			
	Gelatin		Tryptone-glucose extract-milk agar	
	Influent	Effluent	Influent	Effluent
8-2-55	C[a]	C	C	C
8-17-55	C	C	0	0
8-25-55	C	C	C	C
9-13-55	C	C	C	C
12-19-55	16	4	C	C
1-19-56	60	30	--	--

[a]Complete liquefaction.

mismanagement of the Carpenter filter and considering values obtained in random checks of two other slow sand filter installations, a filter effluent of less than 20 units of turbidity would be expected, even with extremely high influent turbidities. Properly operated slow sand filters consistently produced a filtrate of less than 15 units of turbidity when the influent turbidity was less than 40 units. Effluent turbidities of less than 10 units generally have been reported by other investigators (32, 34, 42, 45).

Apparent color. Fair and Geyer (26) indicate that slow sand filters, without the aid of coagulants, will remove 30 percent of the natural color in water. Hale (34), using a raw water which averaged 173 units of color, obtained a 78 percent reduction in color by plain sedimentation and slow sand filtration. Hill (42) reported a greater percent reduction

Table 14. Standard plate and coliform counts in the pond and slow sand filter influent and effluent, Carpenter installation

Sampling date	Standard plate count number/ml			Coliform count number/100 ml		
	Pond surface	Filter influent	Filter effluent	Pond surface	Filter influent	Filter effluent
1958						
3-21	1000	1300	TNC[a]	0	0	0
4-19[b]	600	920	--	0	0	-
5-17	1000	--	400	0	-	0
8-13[c]	1000	13000	3600	0	0	0
9-2	630	440	260	0	0	0
10-3	300	180	25	2	2	15
10-24	550	380	21	10	5	0
10-31	250	140	30	0	0	0
11-28	150	160	46	0	2	3
12-29	480	--	330	0	-	0
1959						
2-25[d]	TNC[e]	TNC[e]	TNC[e]	330	430	180
3-20[f]	5600	8800	8400	0	6	0

[a]TNC, too numerous to count, 3000+ organisms.

[b]Pond level at top of barrel inlet; about 5 feet of head loss through clogged filter.

[c]Filter sand was replaced on 8-10-58.

[d]Spring overturn in process; water highly colored and frothy; 1/3 inch of rain with large volume of snow melt on 2-23-59.

[e]TNC, 3000+ organisms.

[f]Filter sand was replaced on 3-1-59.

for the first 42 days of a filter run. The effluent color was never greater than 5 units when the influent averaged 50 units of color.

Microorganisms. Babbitt and Doland (3) indicate that properly operated slow sand filters will remove 98 to 99 percent of the bacteria from the raw water, but that slow sand filtration may be insufficient to prevent the passage of pathogenic bacteria. Fair and Geyer (26) state that "the larger microorganisms, including the algae and diatoms, are readily removed by filtration. However, Amerman (2) reported that algae as large as 21 microns in diameter passed through a sand which had an effective size of 0.24 mm and a uniformity coefficient of 1.92. In general, even though a reduction in microorganism population occurred, many investigators reported that the filtrate was not of acceptable bacteriological quality according to Public Health Service drinking water standards (2, 25, 32, 34, 42, 74, 85).

Sand specifications. Various specifications for slow sand filtering media have been proposed. Babbitt and Doland (3) indicate that an effective size of 0.35 mm and a uniformity coefficient of about 1.75 is generally specified for municipal slow sand filters. Fair and Geyer (26) indicate an effective size range of 0.25 to 0.35 mm and a uniformity coefficient range of 2.0 to 3.0 as being acceptable sand specifications. An effective size of 0.3 mm and a uniformity coefficient of 2.5 were given as the values most commonly used for municipal slow sand filters.

Experimental and farm-installed slow sand filters for pond water treatment have included sands ranging in effective size from 0.25 to 0.50 mm and in uniformity coefficient from 1.5 to 3.0 (2, 32, 34, 42, 45). An evaluation of the results reported by these investigators does not provide conclusive evidence which would support more restrictive limits on the effective size and uniformity coefficient.

Filtering rate. An evaluation of results, obtained by these same investigators and in this study, indicates that the average filtering rate should not exceed 70 gallons per day per square foot of surface area. Higher filtering rates resulted in less volume of filtrate per square foot of filter surface and in deeper penetration of removed material into the sand bed (32, 34). A filtering rate of 25 gallons per day per square foot has generally yielded a larger volume of filtrate with less penetration of removed material than 50 gallons per day per square foot. Daniel[1] reported that the length of run was increased about five times when a filter which had previously been operating at 50 gallons per day per square foot of surface area was reduced to 25 gallons per day per square foot of surface area.

Experimentally-controlled or properly managed field-installed slow sand filters generally have produced a volume of filtrate in the range of 2000 to 3000 gallons per square foot of filter surface when the filtering rate was in the range of 50 to 70 gallons per day per square foot and when the raw water turbidity was generally less than 40 units.

Filter media other than sand. Filter media other than sand have been used for slow rate filters. Guyer (32) reported that anthracite filter media permitted considerably longer filter runs and that eight times as much water could be filtered through the anthrafilt as for

[1]Daniel, E. R., Agricultural Engineering Department, Oklahoma State University, Stillwater, Oklahoma. Information on pond water treatment. Private communication. 1954.

sand with the same resulting head loss. The average turbidity reduction for both sand and anthrafilt media was 74 percent when the influent varied from 12 to 20 units of turbidity. The filtering rate was 69 gallons per day per square foot of filter area.

Using a filtering rate of 144 gallons per day per square foot through 16 inches of pea gravel, Heiple (38) reported an average filtrate turbidity of 24 units when the water turbidity averaged 68 units. Although the filter was operated for nearly a year, no measurable head loss developed.

Conclusions: Conscientious management is essential for the satisfactory functioning of a slow sand filter.

A properly designed and operated slow sand filter will generally produce 2,000 to 3,000 gallons of filtrate per square foot of filter surface for each run if the filtering rate is in the range of 50 to 70 gallons per day per square foot and the raw water turbidity is generally less than 40 units. Higher filtering rates cause a decreased volume of filtrate per run, increased frequency of cleaning and a deeper penetration of sediment into the filter bed. Filtering rates of less than 50 to 70 gallons per day per square foot may be desirable when the raw water turbidity exceeds 40 units.

A filter effluent of less than 20 units of turbidity can usually be expected even with extremely high influent turbidities. If the influent turbidity is less than 40 units and the filtering rate is less than 70 gallons per day per square foot, a slow sand filter will generally produce a filtrate of less than 10 units of turbidity.

Slow sand filter media ranging in effective size from 0.25 to 0.50

mm and in uniformity coefficient from 0.5 to 3.0 apparently produce similar results with respect to turbidity reduction and volume of filtrate per run. Anthrafilt, as a fine-grained media, is superior to sand with respect to the volume of filtrate produced per run. Pea gravel, as a coarse-grained media, will effectively reduce highly turbid water to 40 units of turbidity or less. Extremely long runs at faster filtering rates are possible without producing a measurable head loss.

Fine-media, slow sand filters will remove 30 to 90 percent of the color from pond water. However, the filtrate color level may sometimes exceed the desirable maximum of 10 units for drinking water.

Slow sand filtration will generally reduce bacteria counts but will not consistently produce a coliform-free effluent. Food-spoilage and milk-spoilage bacteria will almost always be found in the effluent.

Turbidity and bacteria levels in the filtrate will generally be higher following sand replacement until the filter has gone through the required aging or ripening period. Dirty replacement sand will also cause increased turbidity and bacteria levels in the filter effluent.

Total hardness in the filtrate may be slightly increased by water filtration through one to three feet of sand, but the amount of increase will generally be less than 10 mg/l.

Pressurized rapid sand filters

An evaluation of the rapid sand filter in the Wallace installation as a separate unit was not possible since it was connected in series with a granular carbon filter. An evaluation of the combined effect of the two filters indicated a slight reduction in turbidity as shown in Figure 20. The influent to these filters had an average turbidity of 5 units with a maximum of 15 units. The effluent had an average turbidity of 3 units with a maximum of 10 units.

The data showed no apparent effect of the combined filters on hardness, alkalinity, pH and nitrate concentrations.

Hill (42) observed that very little color reduction took place at influent values less than 20 units of color. However, a color reduction of approximately 50 percent was obtained when the influent exceeded 30 units of color. He observed an average reduction of about 3 units in the effluent turbidity when the influent turbidities were less than 15 units. Turbidity was reduced to an acceptable level only after about 2 weeks of operation.

Ludwig[1] obtained an average turbidity reduction of 42 percent with a pea gravel and coarse sand roughing filter. The pressurized rapid sand filter was operated at a filtering rate of about 2 gallons per minute per square foot of surface area. The filter media consisted of 1-1/2 inches of coarse sand and 2 inches of pea gravel. Filtering river water which contained an average of 33.6 units of turbidity, he obtained a filter effluent which contained an average of 19.4 units of turbidity.

Conclusions: Commercially available, rapid sand filters, operated without chemical treatment, will remove 20 to 30 percent of the turbidity units. For more turbid water, a pressurized rapid sand filter will cause a greater percent reduction in turbidity, but the effluent will probably contain more turbidity than the desired maximum of 10

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[1]Ludwig, D. D., Civil Engineering Department, Iowa State University of Science and Technology, Ames, Iowa. Information on rapid sand roughing filter. Private communication. 1961.

units for drinking water.

Commercially available, rapid sand filters will remove about 50 percent of the apparent color in raw water when the influent exceeds 30 units of color. They are less effective in color removal when the influent contains less than 20 units of color.

Pressurized carbon filters

Activated carbon filters are frequently used to remove undesirable odors and tastes from pond water. The odors and tastes associated with algae and diatoms, as well as certain chlorophyllaceous protozoa, may remain unchanged in intensity unless treatment processes especially adapted to the removal of odor-producing and taste-producing substances are included in a pond water treatment system (26). Activated carbon will remove the chlorine residual from chlorinated water supplies in addition to the undesirable pond water odors and tastes.

Granular carbon filters. A granular carbon filter in the Wallace installation was observed in this investigation. It was effective in reducing the chlorine residual to 0.1 mg/l or less. The maximum chlorine residual observed in the influent was 1.0 mg/l. Similar results were reported by Hill.[1] He consistently obtained an effluent residual of less than 0.4 mg/l of chlorine when the influent chlorine residual was less than 1.5 mg/l. He also obtained an average reduction in color of approximately 5 units when the influent color was 20 units or less, and an average reduction in turbidity of approximately 2 units when the

[1]Hill, R. D., Agricultural Engineering Department, Ohio State University, Columbus, Ohio. Information on cartridge and carbon filters. Private communication. 1961.

influent turbidity was 10 units or less.

Precoat carbon filters. Several replaceable precoat carbon filters were observed in the Williams installation during the course of this investigation. A chlorine residual was never observed in the precoat carbon filter effluent even when the influent chlorine residual exceeded 5 mg/l. Although odor tests were not made, odors and tastes characteristic of pond water were apparently reduced to an acceptable level, since no complaints were received from the family who regularly drank the treated pond water.

The effect of a precoat carbon filter on turbidity reduction, as observed in the Williams installation, is shown in Figure 22. Effluent turbidity was consistently less than 10 units even when the influent turbidity exceeded 50 units. Effluent turbidities averaged 3 units. Influent turbidities averaged 18 units. Apparent color was also consistently reduced to 10 units or less even when the influent color was as high as 125 units.

The precoat carbon filter had no apparent effect on pH, total hardness and total alkalinity. It was effective in removing precipitated iron. The iron was oxidized and precipitated by the chlorination process and removed on the precoat carbon filter. Iron content of the precoat carbon filter effluent was consistently 0.1 mg/l or less when the influent iron content ranged from 0.2 to 0.5 mg/l.

The excellent effectiveness of the precoat carbon filter in removing precipitated iron and turbidity was the major factor which limited the useful service life of a replacement filter cartridge. Failure was not due to an undesirable chlorine residual in the filter effluent, but was due to an inadequate flow rate. Flow rate reduction resulted from the accumulation of turbidity and precipitated iron. Tested under field conditions and supplying the drinking and culinary water requirements for a family of four, the average life for an Everpure C-3 precoat carbon filter was about four months. The average volume of filtrate produced by a C-3 filter in a service life of four months was 1200 gallons.

As determined by Guillaume (31), a C-3 filter contains approximately 125 grams of activated carbon which is distributed over 2.6 square feet of septum area. Laboratory tested under simulated intermittent operation of 2 minutes on and 4 minutes off, the C-3 filter produced an average of 2400 gallons of filtrate before failure occurred (31). By definition, filter failure occurred when the chlorine residual in the filtrate exceeded 0.3 mg/l. An influent chlorine residual of 5 mg/l was maintained under laboratory conditions.

Following an investigation of Everpure precoat carbon filters, Renn[1] reported that these filters were substantially finer than the conventional diatomite filter, and that the filter satisfactorily removed all spherical cysts in the size range of 8 to 12 microns. Therefore, it was concluded that this filter would also remove all cysts in the size range common to the water-borne pathogen, Entamoeba histolytica.

Conclusions: Granular and precoat carbon filters will remove undesirable tastes and odors from pond water in addition to the chlorine residual from chlorine disinfected water.

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[1]Renn, C. E., Department of Sanitary Engineering, Johns Hopkins University, Baltimore, Maryland. Information on the removal of cysts by Everpure filters. Private communication. 1960.

Both types of filters will reduce color and turbidity levels, but the precoat carbon filter is considerably more effective. The precoat carbon filter will consistently lower both turbidity and color to satisfactory levels below 10 units even when influent turbidity and color concentrations exceed 50 units.

The precoat carbon filter will effectively remove precipitated iron, the cysts of E. histolytica, and all other foreign matter which is larger than 8 microns in diameter. However, the life of the precoat carbon filter is shortened in proportion to the amounts of precipitated iron and turbidity which it removes.

Other pressurized filters

Several fine-media, pressurized filters have been tested to determine their effectiveness in removing turbidity and color from pond water.

Diatomaceous earth filter. Amerman (2) reported that a diatomaceous earth filter would not consistently produce water of satisfactory physical or chemical quality. Laudenschlager (52) found that the successful operation of a diatomaceous earth filter required thorough and careful execution and that unsatisfactory effluent turbidities occasionally occurred without determinable cause. Frequent attention was required because of the extreme variation in operating conditions imposed on the filter by the changes in pond water quality.

Cartridge filters. Results obtained by Laudenschlager (52) indicated that a cartridge filter with a 5 micron pore size was unsatisfactory for filtering water containing more than 6 units of turbidity unless a diatomaceous earth precoat was provided.

Cellulose fiber and felt filters. Hill (41), after testing cellulose fiber and felt filters, reported that the filters caused no significant change in color and turbidity when the influent contained less than 30 units of color and 10 units of turbidity. In laboratory tests, with influent turbidities ranging from 25 to 40 units, the cellulose fiber filter reduced influent turbidities about 70 percent. He concluded that the filters apparently had no application in the filtration of pond water as a secondary filter. Further testing as a primary filter was needed on water of higher turbidity.

Conclusions: Additional development and testing of diatomaceous earth, cartridge, cellulose fiber and felt filters are required before the applicability of these filters for pond water treatment can be fully evaluated. Available information indicates that the diatomaceous earth filter as presently constituted is not readily adaptable to pond water treatment because of the variable quality of the influent. Cartridge, cellulose fiber or felt filters, some of which are rated as having a pore size as small as 5 microns, apparently have limited application as a secondary, finishing filter in a pond water treatment system.

Effect of mechanical filtration on turbidity removal. To measure the effect of simple, mechanical filtration on the removal of pond water turbidity, pond water samples were filtered through Whatman No. 12 filter papers. The results are shown in Table 15 as an array in a descending order of raw water turbidities. A comparison of raw water turbidities with filtrate turbidities indicates that the filtrate turbidity is not a straight-line function of the raw water turbidity and that the pond source and date of sampling were not influential factors. A possible

Table 15. Turbidity removal by filtration through Whatman No. 12 filter paper

Sampling date	Pond owner	Turbidity units	
		Untreated surface water samples	Whatman No. 12 filter paper filtrates
1958			
8-23	Wolfe	73	2
7-28	Wolfe	62	6
8-13	Wolfe	43	7
5-17	Carpenter	40	4
6-13	Wolfe	31	1
4-19	Williams	31	1
4-19	Carpenter	28	4
8-13	Carpenter	27	7
3-23	Carpenter	24	13
8-13	Williams	20	11
7-28	Wallace	20	11
8-23	Williams	19	10
6-13	Wallace	17	4
5-17	Wolfe	16	4
4-19	Wallace	15	6
8-23	Wallace	14	10
5-17	Williams	13	7
6-13	Williams	12	2
7-28	Wallace	12	8
4-4	Williams	11	6
3-21	Williams	11	4
5-17	Wallace	10	4

significance may exist in the consistently low filtrate turbidities for samples obtained from the Wolfe pond. The higher raw water turbities from this small, shallow pond were affected by algal growths which were more easily removed by the filter paper than colloidal turbidity.

Conclusions: A fine-media, finishing filter should have a mechanical filtering capability equal to or exceeding Whatman No. 12 filter paper if it is to produce a desired filtrate turbidity of 10 units or less. The resulting filtrate turbidity is not a straight-line function of the raw water turbidity as it occurs in typical pond water.

Effect of disinfection methods on bacterial quality

Chlorination and heat treatment were effective in reducing total bacteria counts and in eliminating coliform counts. Food-spoilage and milk-spoilage organisms were reduced in number but not completely eliminated by either of the disinfection methods. Bacteria counts were frequently higher in the dechlorinated water than in the chlorinated water due to recontamination during carbon filtration.

The bacteriological analyses in Table 16 indicate that chlorination materially reduced the total number of bacteria and the coliform-like bacteria. However, all food-spoilage and coliform-like bacteria were not destroyed by chlorination. Only on one day of the six sampling dates was the cold water chlorine residual at the desired level of 3 mg/l. Usually it was maintained by the farm tenant at a level less than 1 mg/l. When the desired 3 mg/l residual was maintained, practically all coliform-like bacteria and those bacteria which normally cause milk or food spoilage were eliminated.

Heat treatment within the water heater caused a decrease in bacteria

Table 16. Bacteriological analyses at various sampling points, Williams installation, 1955-56[a]

Sampling points	Total bacteria, no./ml		Coliform-like bacteria, no./ml		Food-spoilage bacteria, no./ml	
	N.A.	T.G.E.	E.M.B.	Desoxy.	Gelatin	T.G.E.-milk
Pond surface	1200	1535	614	16	C[b]	C
Well beside pond	1565	1290	53	5	C	C
Storage cistern at house	705	1340	88	2	C	C
Chlorinated cold tap[c]	125	20	2	0	O-C	C
Chlorinated hot tap	28	312	0	0	O-C	O-C
Dechlorinated cold tap	1080	1266	7	0	O-C	C

[a]Average of six samplings from 8-2-55 to 1-19-56.

[b]C, complete liquefaction; O-C, either no colonies or complete liquefaction.

[c]Chlorine residuals varied as follows:
Chlorinated cold tap - 0.4 to 3.0 mg/l.
Chlorinated hot tap - none to 0.2 mg/l.
Dechlorinated cold tap - none to a trace.

counts. The hot water system was maintained in the temperature range of 134 to 140° F. The combined effect of chlorine and high temperature was generally more destructive to all types of bacteria than the effect of chlorine alone. Apparently the hot water system had a high chlorine demand since a lower chlorine residual was observed in the hot water than in the cold water.

Total bacteria counts were higher in the carbon filter effluent than in the influent. Apparently, the carbon filter served as a source of bacterial recontamination.

Similar results were obtained in the 1958-59 testing period, Table 17. The standard plate and coliform counts were reduced whenever a chlorine residual was present. Considerable difficulty was encountered in maintaining a continuous and fairly constant chlorine residual. However, no coliforms were observed in the precoat carbon filter effluent regardless of the presence or amount of chlorine residual. In contrast, the standard plate count was occasionally higher in the precoat carbon filter effluent than in the water which had not been chlorinated. Apparently bacteria were carried into the filter during the periods when a chlorine residual was not present. They were then able to continue their existence and to multiply in the chlorine-free medium within the carbon after chlorination was resumed.

A Pseudomonous bacterium contributed to the high carbon filter effluent counts on October 24 and 31. Quite possibly this organism was already in the carbon filter at the time of installation. The Pseudomonous bacterium was later isolated from the infected carbon filter. Laboratory experiments indicated that the chlorine-killing dosage for this particular bacterium exceeded 20 mg/l and that it had definite proteolytic properties.

Data obtained from the Wallace installation in 1958-59, Table 18, indicate that the normal chlorination procedure provided a coliform-free effluent but not a bacteria-free effluent. The additional chlorine contact time provided within the rapid sand filter apparently caused the reductions in the standard plate counts on August 23 and September 2, as

Table 17. Bacteriological analyses at various sampling points, Williams installation, 1958-59

Sampling date	Standard plate count, no./ml				Coliform count, no./100 ml				C.R.,[a] mg/l
	Pond surface	Cistern	Pre-carbon[b]	Post carbon	Pond surface	Cistern	Pre-carbon	Post carbon	Pre-carbon
1958									
8-13	680	1300	5	10	0	-	0	0	6.0
8-23	4600	4200	-	-	0	0	-	-	-
9-2	340	5600	390[b]	150	0	0	30[b]	0	0
10-3	460	230	1	8	3	0	0	0	6.0
10-17	200	230	0	2	40	0	0	0	10.0
10-24	-	175	6	340[c]	-	5	0	0	2.0
10-31	200	190	2	TNC[d]	55	180	0	0	1.5
11-28	500	1500	2	2	33	TNC	0	0	3.0
1959									
2-25	TNC	560	-	20	0	8	-	0	0
3-20	360	-	290	300	16	-	1	0	0

[a]C.R., Chlorine residuals in the carbon filter effluent were always zero.

[b]Chlorination equipment could not be serviced on 8-23-58; high standard plate and coliform counts due to no chlorination.

[c]Carbon filter was changed on 10-17-58; high count due to green-pigmented <u>Pseudomonous</u> bacterium which may have been in the filter when installed.

[d]TNC, Too numerous to count due to the persisting green-pigmented bacterium.

Table 18. Bacteriological analyses at various sampling points, Wallace installation, 1958-59

Sampling date	Standard plate count, no./ml			Coliform count, no./100 ml			Chlorine residual, mg/l	
	Pond surface	Hose bib[a]	Cold tap[b]	Pond surface	Hose bib	Cold tap	Hose bib	Cold tap
1958								
4-19	710	-	11	0	-	0	-	-
5-17	500	-	5	0	-	0	-	0.1
6-13	660	-	9	98	-	0	1.0	0
7-28	2700	-	45	0	-	0	-	0
8-13	270	-	15	0	-	0	0.1	0.1
8-23	2400	490	9	0	0	0	0.8	0
9-2	250	42	11	0	0	0	0.4	0
10-3	90	1	3	3	0	0	0.4	0
10-17	20	14	12	0	0	0	0[c]	0
10-31	80	2	4	0	0	0	0.4	0
11-28	140	1	4	0	0	0	0.3	0
12-29	-	1	4	-	-	-	0.2	0
1959								
2-25	4000	-	5	34	-	0	-	-
3-20	3300	500	250	30	0	0	0	0

[a]Water had been filtered through a pea gravel trench filter and chlorinated.

[b]Water had been filtered through a pressurized rapid sand filter and a granular carbon filter in addition to the treatment described in footnote a.

[c]Break in chlorine solution injection tubing.

indicated by the differences in counts obtained for the hose bib and cold tap sampling points.

Lack of a chlorine residual on October 17 was caused by a break in the chlorine solution injection tubing. No mechanical failure could be found to explain the lack of chlorine residual on March 20. The increased chlorine demand of the raw water as a result of the spring overturn and runoff was the probable cause for the absence of a chlorine residual.

The effect of heat on bacteria counts was observed at the Wolfe installation, Table 19. The water received no treatment other than filtering through a pea gravel filter bed and heating to a temperature which ranged from 140 to 150° F. A consistent reduction in standard plate counts was observed. A coliform count was not observed in the pond water samples until after the pond had been filled with river water. Immediately following the sampling on September 2, the pond was filled with river water which had a standard plate count of 1400 per ml and a coliform count of 80 per 100 ml. Lesser counts were observed in the sample taken from the pond on October 3. No coliforms were observed in the hot water sample.

Subsequent to the release of preliminary information concerning the effect of water heating in the conventional water heater on coliform counts (6), the Robert A. Taft Sanitary Engineering Center completed an intensive investigation of water pasteurization (30). The recommended water pasteurizer, developed as a result of this investigation, has a 15-second holding time at a temperature of 161° F. All coliform organisms were destroyed by this exposure to heat.

Table 19. Bacteriological analyses at various sampling points, Wolfe installation, 1958

Sampling date	Standard plate count, no./ml		Coliform count, no./100 ml	
	Pond surface	Hot tap[a]	Pond surface	Hot tap
1958				
5-17	230	20	0	0
6-13	1100	10	0	0
7-28	300	20	0	0
8-13	240	110	0	0
8-23	430	260	0	0
9-2	320	-	-	-
10-3[b]	110	50	10	0

[a]Water temperature varied between 140 and 150° F. Water had been filtered through a pea gravel filter bed.

[b]Pond was filled with river water subsequent to the sampling on 9-2-58.

Hill (42), reporting on bacteriological analyses of effluent from a water pasteurizer, indicated that thermoduric, food-spoilage organisms were not killed by pasteurization, and that they generally ranged from 50 to 200 per ml in the pasteurizer effluent.

Conclusions: Either chlorination or pasteurization will reduce the total number of bacteria and destroy all coliform bacteria in filtered pond water. Food-spoilage and milk-spoilage organisms will be reduced in number but will not be completely eliminated.

Post-contamination of dechlorinated water can occur within a carbon filter. Bacteria may enter the carbon filter during periods of inadequate chlorination, or the bacteria may be in the filter media at the time of installation. The bacteria can continue to multiply in the chlorine-free environment within the carbon after adequate chlorination is resumed.

Increased bacteria counts can occur in the disinfected water from either a chlorination-dechlorination system or a water pasteurization system due to the existence of chlorine-resistant or heat-resistant organisms which may not be destroyed in the disinfection process. This problem will more likely occur in a water pasteurization system which requires storage for the disinfected water.

The successful operation of a chlorination system is subject to mechanical failure, human error and variable water quality. Additional development of chlorination equipment is necessary to eliminate possible causes of failure.

CONCLUSIONS

The conclusions resulting from this study can be grouped as follows: (1) the effect of various factors on the properties of water within the pond and (2) the effect of various water treatment system components or treatment procedures on water properties.

Effect of Factors on Properties of Water Within the Pond

Pond age significantly affects the color, turbidity and nitrate concentrations in pond water. Newly-constructed ponds contain more color, turbidity and nitrate than ponds which are two or more years old unless other factors are more dominant than pond age.

Nitrate concentration in pond water, particularly in older ponds, generally does not constitute a health hazard. Grazing of a grassed watershed does not materially affect the nitrate concentration in the pond water since established biological life in older ponds apparently consumes the nitrogen soon after it enters the pond.

Dilution of pond water by runoff decreases the mineral content in the water. Newly-constructed ponds generally contain water of lower mineral content than older ponds since the new ponds are filled by recent runoff. Mineral content increases with time in all ponds due to evaporation until runoff water of low mineral content again dilutes the pond water.

Watershed cover and use influence pond water properties. A grassed watershed has a stabilizing influence on the physical and chemical properties of the pond water. In contrast, great variability in water properties occurs in ponds with cultivated watersheds. Ponds with cultivated watersheds generally contain water of higher mineral content than ponds with grassed watersheds. Coliform organisms occur more frequently in ponds with grazed watersheds than in ponds with cultivated or mowed watersheds.

Discounting the short-term influence of other factors, a relationship exists between hardness and turbidity levels. A high hardness content and generally associated high specific conductance is related to a low turbidity level. Pond water high in turbidity will generally be low in hardness, assuming that the suspended solids are predominantly colloidal material and do not include extensive algal and other vegetative material.

Soil properties influence pond water properties. Runoff water from a youthful, fertile soil is higher in hardness and total mineral content than runoff from an older soil which is more leached and lower in readily soluble minerals.

An ice cover has a stabilizing influence on pond water properties and low turbidity and color levels will result. In contrast, the fall and spring overturns disturb the pond and the highest turbidity and color levels will generally occur following an overturn. Spring overturns usually cause more abrupt and greater changes in water properties than fall overturns. Dilution water, as the result of either snow melt or rainfall, will lower the hardness, alkalinity and pH levels. Lime applications or the addition of other soil amendments to the watershed can materially affect pond water properties. In general, pond water will be highest in color, turbidity and odor in the spring months in the northern latitudes.

The relationship of the watershed area to the pond storage capacity is more significant as it affects the color of the pond water than the singular effect of either the watershed area or pond storage capacity. An adequate watershed-to-pond-size ratio is desirable to maintain a fairly constant pond water level near overflow capacity. A fluctuating water surface may increase the color concentration due to the submergence and decay of vegetation with a rising water level.

Tests and inquiries direct to pond water consumers indicated that iron and manganese concentrations were not excessive in Iowa pond water supplies. However, combined iron and manganese concentrations in pond water exceeding 0.3 mg/l have been reported by investigators in other states. Treatment for iron and manganese removal may be desirable for some pond waters.

A pond disturbance by an overturn or by runoff entering the pond increases the bacteria count in the water near the pond surface. Seasonal variation in solar radiation also influences bacteria counts. Coliform organisms persist longer in the cooler months than in the warmer months.

Effect of Treatment System Components or Procedures on Properties

A float-suspended inlet located in the upper portion of the pond permits the withdrawal of higher quality water than any other type of inlet which might be placed on or near the bottom of the pond. The desirable depth of submergence can range between 24 and 48 inches in farm ponds which are at least 8 feet deep. This depth range will avoid concentrated algal growth near the surface and higher color, turbidity and odor levels near the bottom. A minimum depth of 24 inches is necessary in Iowa to place the inlet below the depth of ice formation.

Integral filters remove suspended solids from pond water. The sand-filled trench filter is more effective in turbidity reduction than the trench filter which contains a coarser filtering media. However, the finer media is more subject to rapid clogging. An integral filter is difficult to clean unless the pond water level is lowered. Replacement of the filter media may be necessary to restore the original filtering rate.

Pea gravel filtering media, in either a trench filter or a filter bed, serves as an effective roughing filter. Generally, pea gravel filtering media will produce an effluent containing less than 20 units of turbidity, but it will not consistently produce an effluent containing less than 10 units.

Effluent from integral filters is always higher in total hardness and total alkalinity than untreated water in the upper portion of the pond. In general, the quality of effluent from a pea gravel filter bed is superior to the effluent from a buried collector tile or pea gravel trench filter. None of the integral filters will consistently produce effluent which will satisfy the U. S. Public Health Service drinking water standards.

Pond treatment with calcium or aluminum sulfate will satisfactorily reduce color and turbidity in highly turbid ponds. Coagulation-sedimentation immediately prior to slow sand filtration is difficult to control and unsatisfactory results will often occur.

Conscientious management is essential for the satisfactory functioning of a slow sand filter. A properly designed and operated slow sand filter will generally produce 2,000 to 3,000 gallons of filtrate per square foot of filter surface for each run if the filtering rate is in the range of 50 to 70 gallons per day per square foot and the raw water turbidity is generally less than 40 units. Higher filtering rates cause a decreased volume of filtrate per run, increased frequency of cleaning and a deeper penetration of sediment into the filter bed. Filtering rates less than 50 to 70 gallons per day per square foot may be desirable when the raw water turbidity exceeds 40 units.

A filter effluent of less than 20 units of turbidity can usually be expected even with extremely high influent turbidities. If the influent turbidity is less than 40 units and the filtering rate is less than 70 gallons per day per square foot, a slow sand filter will generally produce a filtrate of less than 10 units of turbidity.

Slow sand filter media ranging in effective size from 0.25 to 0.50 mm and in uniformity coefficient from 1.5 to 3.0 apparently produce similar results with respect to turbidity reduction and volume of filtrate per run. Anthrafilt, as a fine-grained media, is superior to sand with respect to the volume of filtrate produced per run. Pea gravel, as a coarse-grained media, will effectively reduce highly turbid water to 40 units of turbidity or less. Extremely long runs at faster filtering rates are possible with coarse-grained media without producing a measurable head loss.

Fine-media, slow sand filters will remove 30 to 90 percent of the color from pond water. However, the filtrate color level may sometimes exceed the desirable maximum of 10 units for drinking water.

Slow sand filtration will generally reduce bacteria counts but will not consistently produce a coliform-free effluent. Food-spoilage and milk-spoilage bacteria will almost always be found in the effluent.

Turbidity and bacteria levels in the filtrate will generally be higher following sand replacement until the filter has gone through the required aging or ripening period. Dirty replacement sand will also cause increased turbidity and bacteria levels in the filter effluent.

Total hardness in the filtrate may be slightly increased by water filtration through one to three feet of sand, but the amount of increase will generally be less than 10 mg/l.

Commercially available rapid sand filters, operated without chemical treatment, will remove 20 to 30 percent of the turbidity when the influent contains less than 15 turbidity units. For more turbid water, a pressurized rapid sand filter will cause a greater percent reduction in turbidity, but the effluent will probably contain more turbidity than the desired maximum of 10 units for drinking water.

Commercially available rapid sand filters will remove about 50 percent of the apparent color in raw water when the influent exceeds 30 units of color. They are less effective in color removal when the influent contains less than 20 units of color.

Granular and precoat carbon filters will remove undesirable tastes and odors from pond water in addition to the chlorine residual from chlorine disinfected water.

Both types of filters will reduce color and turbidity levels, but the precoat carbon filter is considerably more effective. The precoat carbon filter will consistently lower both turbidity and color to satisfactory levels below 10 units, even when influent turbidity and color concentrations exceed 50 units.

The precoat carbon filter will effectively remove precipitated iron, the cysts of *E. histolytica*, and all other foreign matter which is larger than 8 microns in diameter. However, the life of the precoat carbon filter is shortened in proportion to the amounts of precipitated iron and turbidity which it removes.

Additional development and testing of diatomaceous earth, cartridge, cellulose fiber and felt filters are required before the applicability of these filters for pond water treatment can be fully evaluated. Available information indicates that the diatomaceous earth filter as presently constituted is not readily adaptable to pond water treatment because of the variable quality of the influent. Cartridge, cellulose fiber or felt filters, some of which are rated as having a pore size as small as 5 microns, apparently have limited application as a secondary, finishing filter in a pond water treatment system.

A fine-media, finishing filter should have a mechanical filtering capability equal to or exceeding Whatman No. 12 filter paper if it is to produce a desired filtrate turbidity of 10 units or less. The resulting filtrate turbidity is not a straight-line function of the raw water turbidity as it occurs in typical pond water.

Either chlorination or pasteurization will reduce the total number of bacteria and destroy coliform bacteria in filtered pond water. Food-spoilage and milk-spoilage organisms will be reduced in number but will not be completely eliminated.

Post-contamination of disinfected water can occur when a carbon filter is used for dechlorination. Bacteria may enter the carbon filter during periods of inadequate chlorination, or the bacteria may be in the filter media at the time of installation. The bacteria can continue to multiply in the chlorine-free environment within the carbon after adequate chlorination is resumed.

Increased bacteria counts can occur in the disinfected water from either a chlorination-dechlorination system or a water pasteurization system due to the existence of chlorine-resistant or heat-resistant organisms which may not be destroyed in the disinfection process. This problem will more likely occur in a water pasteurization system which requires storage for the disinfected water.

The successful operation of a chlorination system is subject to mechanical failure, human error and variable water quality. Additional development of automatic defection devices is necessary to insure adequate and continuous chlorination.

RECOMMENDATIONS

General Recommendations

An adequate watershed area to maintain a fairly constant pond water level near overflow capacity is recommended. Advantages are as follows: (1) to provide more runoff to dilute the water already in the pond and thus decrease the mineral concentration in the water; (2) to eliminate excessive pond water level fluctions and thus discourage the establishment of vegetation on the bare banks and in the shallow water; this will decrease the possibility for increased color, taste and odor concentrations in the water due to the decomposition of the vegetation following submergence; (3) to provide a more dependable water supply; and (4) to provide a minimum desirable water depth at all times.

A grassed watershed is recommended since it has a stabilizing influence on pond water properties and contributes less dissolved and suspended solids to the runoff water. A lower mineral content and less fluctuation of pond water properties will result. Moderate grazing of a grassed watershed is permissible if the animals are disease-free.

A grass cover should be established on the pond banks and the disturbed area around the pond to minimize soil erosion and the amount of suspended solids in the pond water.

Fencing of the pond and a de-silting grassed area above the pond is recommended. All animals and fish which would increase the water turbidity should be excluded from the pond.

Chemical treatment of highly turbid water within the pond is recommended to reduce color and turbidity levels.

A float-suspended inlet is recommended to remove water of superior quality from the upper portion of the pond.

A roughing filter, consisting of pea gravel or other coarse-grained media, is recommended to reduce the amount and variable quantity of suspended solids to be removed by the fine-media, finishing filter, and to reduce the chlorine demand of the influent to the finishing filter.

Prechlorination of the finishing filter influent is recommended to oxidize and precipitate iron and manganese, to increase chlorine contact time, to improve the diffusion and mixing of the chlorine solution with the water to be treated and to decrease the fluctuation of the chlorine residual in the disinfected water.

Superchlorination of the finishing filter influent (prechlorination) is recommended to destroy organisms, tastes and odors which are not destroyed by normal chlorination and to compensate for the lack of control over widely varying factors which influence the effectiveness of chlorine disinfection.

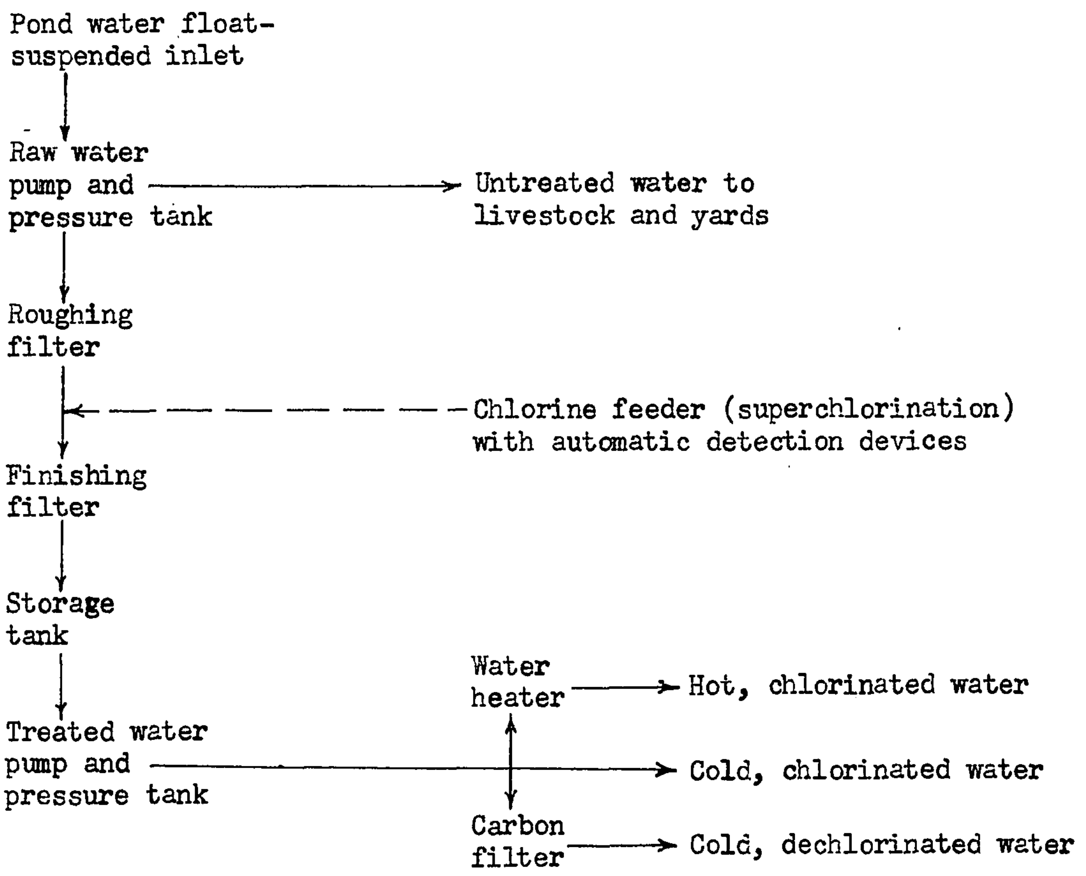
A finishing filter, consisting of sand or other fine-grained media, is recommended to reduce color and turbidity to acceptable levels, and to remove precipitated iron and manganese.

Dechlorination of drinking and culinary water by carbon filtration is recommended to produce a palatable, odor-free water.

Recommendations for a Proposed Pond Water Treatment System

Based on available research data as presented in this report, a complete pond water treatment system should preferably include the components as indicated in the following flow diagram.

Table 20. Flow diagram for a pond water treatment system



The float-suspended inlet, Figure 18, should be adjusted to withdraw water from a depth of 2 to 4 feet below the pond surface. The minimum depth of water at the inlet location should be 8 feet.

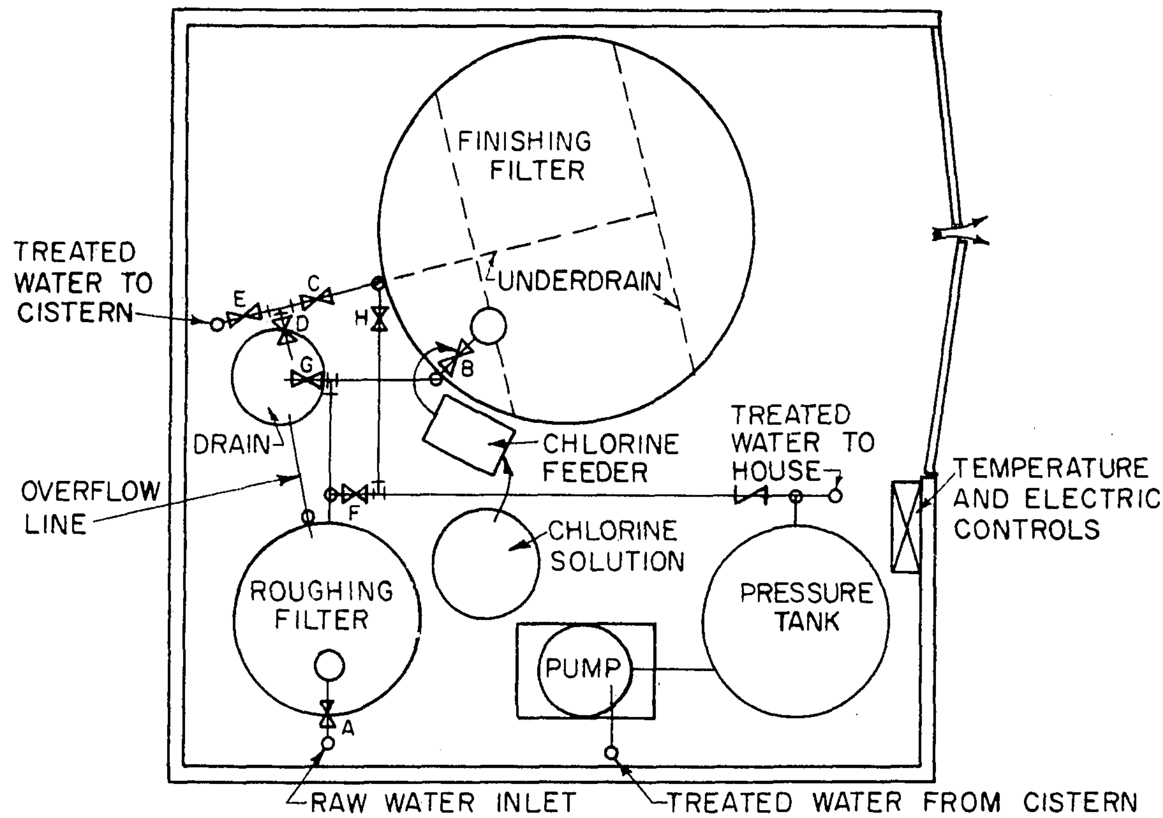
If a shallow-well pump is to be used and the total lift exceeds 20 feet, the raw water pump and pressure tank should be located in an insulated pump house near the pond. If the total lift is less than 20 feet, the raw water pump and pressure tank may be installed in any existing heated building which is suitable and conveniently located, or the pump and pressure tank may be installed in the filter house.

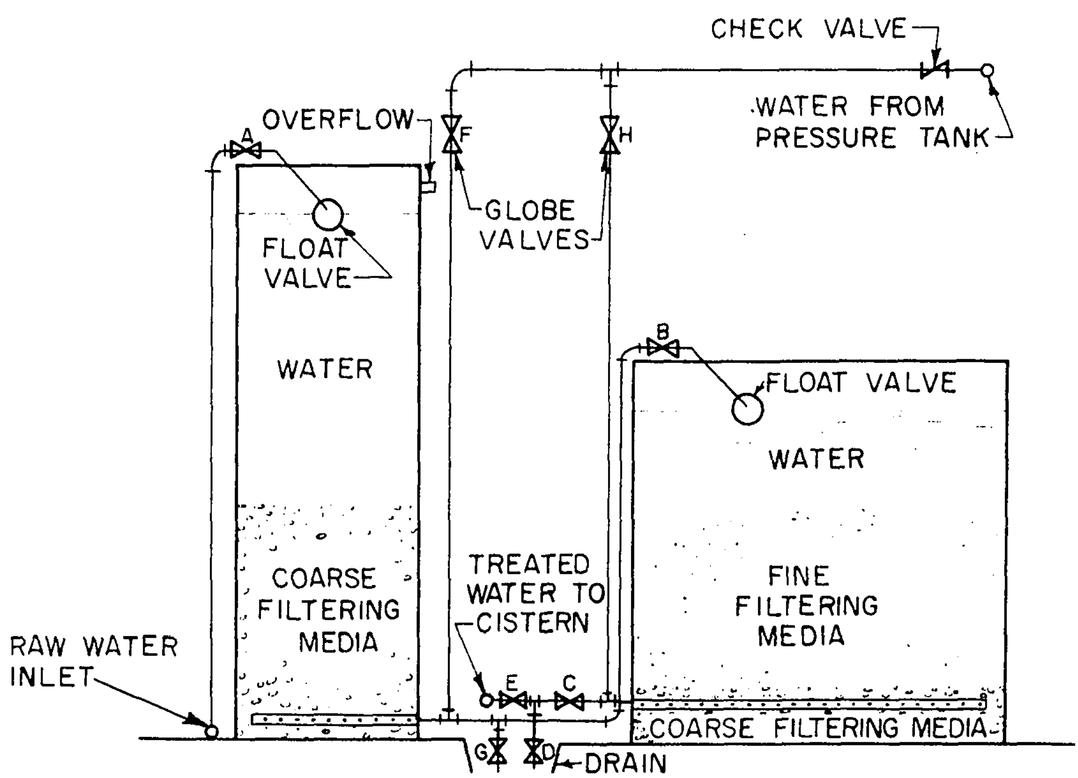
The filter house, Figure 24, should be of adequate height and floor area to permit the installation and servicing of the water treatment equipment.

The roughing filter may be a pressurized, rapid sand filter or a vertical, gravity flow filter as diagramed. A minimum depth of 4 feet of water over 2 feet of pea gravel is suggested for the gravity flow filter. A water depth of 6 feet is preferred. A filtering rate of about 150 gallons per day per square foot of surface area is suggested for the pea gravel filter. The pea gravel filter will require cleaning about once a year.

Effluent from the roughing filter should be superchlorinated at the point of discharge over the finishing filter. A minimum superchlorination factor of 35 (the product of the detention time in minutes and the chlorine residual of the disinfected water in mg/l) is recommended. A chlorine residual of 3 to 5 mg/l is suggested. The chlorinator should be wired to operate simultaneously with the pump. Automatic detection devices should be used to prevent inadequate or

Figure 24. Components of a pond water treatment system within a filter house.


FINISHING
FILTER
UNDERDRAIN
TREATED
WATER TO
CISTERN
E
C
D
H
G
B
DRAIN
OVERFLOW
LINE
CHLORINE
FEEDER
TREATED
WATER TO
HOUSE
F
TEMPERATURE
AND ELECTRIC
CONTROLS
CHLORINE
SOLUTION
ROUGHING
FILTER
PRESSURE
TANK
PUMP
A
RAW WATER INLET
TREATED WATER FROM CISTERN


CHECK VALVE
WATER FROM
PRESSURE TANK
OVERFLOW
A
F
H
FLOAT
VALVE
GLOBE
VALVES
WATER
B
FLOAT VALVE
WATER
COARSE
FILTERING
MEDIA
TREATED
WATER TO
CISTERN
FINE
FILTERING
MEDIA
RAW WATER
INLET
E
C
G
D
DRAIN
COARSE FILTERING MEDIA

discontinuous chlorination.

Several fine-grained media could be used in the finishing filter. A minimum depth of 1 foot of builder's, mason's or plasterer's sand over the pea gravel covered underdrain is suggested. A sand depth of 2 feet is preferred. A maximum filtering rate of about 70 gallons per day per square foot of surface area is suggested for the sand filter. A slower filtering rate is preferred. The sand filter will require cleaning about six times each year.

A float valve must be installed in the cistern to prevent overflow by effluent from the finishing filter. A minimum cistern capacity to store twice the average daily water requirement is suggested. Greater cistern capacity is preferred.

One or more carbon filters should be installed within the home to provide dechlorinated drinking and culinary water. Chlorinated water is recommended for all additional consumptive uses within the home.

Operational and cleaning sequences

Operational sequence, starting with all valves closed:

1. Open A to fill roughing filter; float valve regulates maximum water level over roughing filter.
2. Open B to fill finishing filter; partially close B to regulate the rate of flow through the roughing filter; float valve regulates maximum water level over finishing filter.
3. Batch chlorinate both filters; level the sand in the finishing filter.
4. Open C and D; partially close C to regulate the rate of

flow through the finishing filter.

5. When the effluent is clear, open E and close D; float valve regulates maximum water level in the cistern.

Cleaning sequence for finishing filter:

1. Close A, B and E.
2. Open D to lower the water level to a few inches below the sand surface in the finishing filter.
3. Close D; remove accumulated sediment from the sand surface; level sand surface.
4. Open H until finishing filter is refilled.
5. Close H.

Cleaning sequence for roughing filter by agitation and draining:

1. Agitate the pea gravel and open G to drain; open A and continue agitating the pea gravel until the accumulated sediment is flushed out of the pea gravel.
2. Close G.

Cleaning sequence for roughing filter by backwashing:

1. Open F and backwash through overflow until clean.
2. Close F. (Note: F and H must be located at a higher elevation than the water level in either filter.)

SUGGESTED AREAS FOR ADDITIONAL INVESTIGATION

An evaluation of the information presented in this report indicates that additional investigations are needed in the following areas:

1. Sources of nitrogenous materials, their concentration in pond water and the causes for their reduction within the pond.

2. A comparison of grazing and mowing of grassed watersheds as they affect pond water properties.

3. The properties of pond water as they are affected by various watershed-to-pond size ratios.

4. Procedures which could partially eliminate or temper the abrupt changes in pond water properties as caused by spring and fall overturns.

5. Procedures which could be used following an overturn to more quickly restore a relatively stable condition within the pond.

6. Pond water stratification as it affects water properties and treatment throughout the year.

7. The occurrence and control of algae and other undesirable microorganisms within the pond.

8. Coarse-media filters, both pressurized and gravity flow filters, with respect to their proper design and operation as roughing filters.

9. Fine-media filters, both pressurized and gravity flow filters, with respect to their proper design and operation as finishing filters.

10. The required equipment and operational procedures to reduce or eliminate the problem of inadequate or discontinuous chlorination as caused by variable water properties, mechanical failure and human error.

11. Iron and manganese removal by prechlorination, manganese green

sand and other means which could be incorporated into a pond water treatment system.

12. The effects of prechlorination on water properties and filter performance.

13. The required chlorine dosage and contact time for the destruction of water-borne food-spoilage and milk-spoilage organisms and pathogens.

14. Procedures for the sterilization of carbon filters.

15. The maximum acceptable concentration of each pertinent water property for every consumptive use in a rural home in order to establish standards for water quality which are applicable to rural consumptive uses.

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